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From Lifespan Inequality to Lifespan Inequity

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Abstract

This article introduces a comprehensive framework for defining and quantifying lifespan inequity within a population, grounded in the capability approach. Lifespan inequity (i.e., unfair inequality) is defined as lifespan deprivation due to premature mortality in a life table distribution of ages at death. We introduce the concept of the Minimally Adequate Length of Life as the threshold distinguishing premature deaths from lifespans of “normal length” and propose to quantify it with the adult modal age at death. Further, we propose to quantify lifespan inequity applying the widely used poverty indices from the Sen-Shorrocks-Thon and Foster-Greer-Thorbecke families, which consider the proportion of the life table cohort who die prematurely (incidence), the extent of their lifespan deprivation (depth), and the distribution of the deprivation among those who die prematurely (distribution). To demonstrate the utility of this approach, we apply the framework to quantify lifespan inequity in the United States from 1933 to 2021 and compare it with levels and trends in other high-income countries. The analysis shows that while US lifespan inequity initially declined faster than in other nations, it stagnated from the 1980s onward, resulting in the highest levels by the 2010s, with the COVID-19 pandemic exacerbating lifespan inequity through a sharp rise in the depth of premature mortality. We demonstrate that the measure of lifespan inequity developed in the proposed framework effectively defines, quantifies, and, therefore, assesses the ethical dimensions of inequality in the length of life within a population. This study highlights the essential interplay between demography and philosophy, as philosophical concepts underpin the assumptions and decisions that shape demographic measures and their interpretations.

Keywords Lifespan inequity · Premature mortality · Lifespan inequality · Inequity in the length of life · Capability approach

1 Introduction

Questions about inequalities in the length of life are fundamental to many health research fields, such as demography. Lifespan inequalities are generally examined using either a bivariate (mortality differences between groups) or univariate (mortality differences across individuals) approach (Wolfson & Rowe, 2001). Inequities in the length of life, defined as the ethically problematic inequalities, i.e., inequalities that a society ought to be morally concerned about and act upon, are rarely articulated in either approach. Nevertheless, studies of the bivariate approach to mortality inequality in a given population are often thought to imply normative judgments, as inequalities in the average length of life across the socially meaningful groups are considered as inequitable (Braveman & Gruskin, 2003). On the other hand, univariate studies, i.e., studies of differences in the length of life across individuals regardless of socially meaningful characteristics in a population, are often considered as irrelevant to policy making and ethical analysis (e.g., Asada, 2007; Hausman, 2017). From a policy perspective, proponents of the univariate approach argue that it offers more transparent and comparable overview of the magnitude of inequality as compared to the bivariate approach. The reason is that, with numerous possible ways to define the groupings of individuals in the bivariate approach, a vast amount of detailed information produced can obscure the overall picture of lifespan inequalities (Asada, 2013; Lippert-Rasmussen, 2013). Additionally, when studying individual differences in the length of life, as in the univariate approach, we can make a comprehensive assessment of lifespan inequality across the entire population, reflecting the complete distribution rather than just differences between groups, as in the bivariate approach (Lippert-Rasmussen, 2013). From a moral perspective, the univariate approach to measuring health or lifespan inequality can be appropriate because it aligns with the ethical value placed on health and life. The core argument is that if one accepts health as something of moral significance—whether as a fundamental good, a component of well-being, or a necessary condition for pursuing other values—then individual inequalities in health deserve moral scrutiny (Asada, 2013). Moreover, evaluating inequality at the individual level aligns with ethical principles that treat individuals as the fundamental unit of moral concern, rather than averaging over groups (Lippert-Rasmussen, 2013).

Demographic studies of the univariate approach have typically been motivated by one of three questions. The first concerns the nature of human mortality and longevity, including the potential compression of deaths to older ages (e.g., Fries, 1980; Kannisto, 2000), and whether there is a limit to the human lifespan (e.g., Cheung et al., 2005; Rothenberg et al., 1991). The aim of the second group of studies is to describe differences in the variation of life table ages at death across countries and their changes over time (e.g., Aburto et al., 2023; Van Raalte et al., 2018). The third question concerns formal relationships between statistics of life table age-at-death distributions, for example, between their location and spread (e.g., Aburto et al., 2020; Muszyńska & Janssen, 2016), or how to improve the accuracy of population forecasts by including inequality statistics (Bohk-Ewald et al., 2017). Tremendous improvements in modelling and measurement of lifespan inequalities using the univariate approach have been made over the past few decades. Indices of inequality in length of life have been adopted and adapted for the life table (Hanada, 1983; Myers & Manton, 1984; Shkolnikov et al., 2003; Silber, 1983; Wilmoth & Horiuchi, 1999), and new indices have been proposed (Hakkert, 1987; Shkolnikov et al., 2011). Nevertheless,

because these demographic studies are not based on a theoretical framework informed by an ethical theory that could justify lifespan inequality as ethically objectionable, ethical judgments cannot be made from their results. This paper aims to fill this gap by developing an analytical framework for measuring lifespan inequity resulting from population mortality conditions, using the univariate approach. By “population mortality conditions,” we mean the conditions that influence mortality risk in a study population during a given period, as well as the population’s composition with respect to risk. This risk composition is the result of past conditions and individual behaviors throughout one’s lifetime (Guillot, 2008; Guillot & Canudas-Romo, 2016; Vaupel, 2002). The mortality conditions of a population under study are reflected in the distribution of deaths in a period life table based on age-specific mortality rates during a given period (Preston et al., 2001; Vaupel, 2002). To develop the analytical framework, we follow the three-step procedure (i.e., defining, operationalizing, and quantifying health inequity) proposed by Asada (2005, 2007, 2019).

The three-step procedure was originally developed for the general purpose of measuring health inequities coherently with transparent theoretical underpinnings. Table 1 explains how the three-step procedure is applied and which conceptual foundations influence to build the framework in this study. First, we define lifespan inequity as lifespan deprivation due to premature mortality based on the capability approach, specifically in the version developed by Martha Nussbaum (Nussbaum & Sen, 1993; Nussbaum, 2000, 2011) (Sect. 2.1). Second, we operationalize premature mortality as deaths that occur below what we call the Minimally Adequate Length of Life (MALL), i.e., a threshold age that divides ages at death into those premature and of full length (Sect. 2.2). We propose to measure MALL with the adult modal age at death in a period life table of the study population and measure it specific to sex and population. The development of MALL is informed by the poverty literature, in particular, what is often referred to as the identification problem. Finally, to quantify lifespan inequity, we consider the incidence, depth, and distribution of deaths below MALL and use standard indices, the Sen-Shorrocks-Thorn (SST) and Foster-Greer-Thorbecke indices

Table 1 Development of the framework for measuring lifespan inequity

Step	Decision	Conceptual foundation
Definition	Lifespan inequity is lifespan deprivation due to premature mortality in a period life table	Nussbaum’s version of the capability approach
Operationalization	Premature mortality is deaths that occur below the Minimally Adequate Length of Life (MALL); Set specific to the population; Set specific to sex; Measured by the modal age at death	Identification step in poverty studies
Quantification	Lifespan inequity concerns the incidence, depths, and distribution of deaths below MALL; Measured by Sen-Shorrocks (SST) index or Foster-Greer-Thorbecke index	Aggregation step in poverty studies (aggregation)

(Sect. 2.3). The quantification of lifespan inequity is informed by the poverty literature, in particular, what is often referred to as the aggregation problem.

Our analytical framework is informed by the capability approach for an ethical perspective and by poverty studies for measurement strategies. As the capability approach provides little guidance on the measurement choices necessary to construct this measurement framework, we look to the poverty literature for guidance, specifically on the conceptualization of the MALL and the quantification of lifespan deprivation as lifespan inequity. The reference to poverty studies is justified because both premature death and poverty analyses are interested in quantifying the deprivation of certain basic capabilities (Hick, 2012; Sen, 1992). In addition, both studies share similar measurement problems: identification of a threshold (MALL and poverty line, respectively) and aggregation of respective quantities below the threshold (deprivation of lifespans of deaths below the MALL and income deprivation below the poverty line, respectively).

The issues that arise in the operationalization and quantification steps are both methodological and ethical. There is no existing philosophical theory to guide all these steps, and one might argue that methodological decisions are ultimately subjective. As discussed in the philosophy of science (e.g., Longino, 1990), it is a fundamental tenet of empirical studies that subjective assumptions are necessary in any scientific endeavour. Provided they are carefully formulated and clearly stated, ethical conclusions can be drawn from a measurement framework based on these assumptions; however, their validity is confined to the particular conceptual and empirical setup in which these assumptions hold. As argued by Imenda (2014), a systematically developed measurement framework represents the researcher's specific perspective for exploring, interpreting, or explaining the phenomena under study. Thus, in our case, the proposed measurement framework offers transparent and explicit ethical assumptions for measuring lifespan inequity.

After the development of the framework, we empirically demonstrate it by examining how the United States has performed in terms of lifespan inequity over the period of 1933–2021 in comparison to other high-income countries (Sect. 3). We show that the proposed analytical framework can serve as a guide for the normative interpretation of empirical findings in light of the philosophical theory and the associated assumptions on which the framework is based.

2 An Analytical Framework for Lifespan Inequity

2.1 Defining Premature Mortality as a Capability Deprivation

In this study, we aim to quantify inequities in life expectancy within a population, as determined by its mortality conditions, which are reflected in period mortality rates and summarized in the period life table (see the Introduction for the definition of 'mortality conditions' used in this study). The first step in constructing the framework is therefore to define, according to a chosen philosophical approach, which part of the period life table distribution of the length of life is ethically problematic and why.

Our analytical framework is based on the capability approach (Nussbaum & Sen, 1993; Nussbaum, 2000, 2011), particularly the version developed by Nussbaum (2000, 2011). We do not claim that the capability approach provides the most appealing and defensible view.

Rather, we demonstrate how the measurement framework can be constructed based on one of the plausible theories to define lifespan inequity. We discuss alternative theories in the discussion section.

Sen and Nussbaum distinguish *capabilities*—what people can do (e.g., literacy) from *functionings*—what people actually do and are (e.g., reading and writing). They consider that these capabilities are critical for persons to flourish, i.e., to be and do what they value, regardless of their functionings. For example, literacy (capability) is important whether a person chooses to become a writer (functioning) or an artist (functioning). They also consider that all persons in a population should satisfy some threshold of minimum capabilities so all members of a society can stand equally (Sen, 1996). Sen is deliberately ambiguous about what constitutes capabilities (as stated, for example, in Sen (2009)¹, but Nussbaum (2000, 2011) provides a list of ten central capabilities: life; bodily health; bodily integrity; sense, imagination, and thought; emotions; practical reason; affiliation; other species; play; and control over one’s environment. For life, the first capability in the list, Nussbaum explains, “Being able to live to the end of a human life of normal length; not dying prematurely, or before one’s life is so reduced as to be not worth living” (2011, p.33). Thus, the connection between Nussbaum’s version of the capability approach and the length of life is direct: a human *life of normal length* is one of the capabilities that all persons should have to flourish. Deaths that occur at younger ages than the normal length of life can be considered as unfair because such deaths are deprivation of a life of normal length, one of the central capabilities.

To summarize, according to the capability approach, in a just society (or, more precisely, a society that cares about justice) we are concerned about the deprivation of lifespan that results from premature mortality, that is, deaths that occur below a threshold age. This is because dying prematurely deprives individuals of a central capability that is necessary for their equal standing in the society.

2.2 Operationalizing the Concept of Premature Mortality

For life, the first capability in Nussbaum’s list, a threshold age separates premature and non-premature deaths². As a philosophical theory, however, the capability approach does not specify how to identify and measure this threshold age. Our second step in developing an analytical framework for lifespan inequity is therefore to operationalize the concept of premature mortality. We call this threshold age the Minimally Adequate Length of Life

¹ The importance of long life is, however, often emphasized by Sen. For example, in his 2002 article (Sen, 2002, p.660), he writes that “any conception of social justice that accepts the need for a fair distribution as well as efficient formation of human capabilities cannot ignore the role of health in human life and the opportunities that persons, respectively, have to achieve good health – free from escapable illness, avoidable afflictions and premature mortality.”

² Concepts of premature mortality differ substantially across scientific disciplines. One common approach defines all deaths occurring before a biological maximum lifespan as premature, as seen in as e† (life disparity) and selected measures belonging to Years of Life Lost (YLL). In some YLL measures premature mortality is defined as deaths occurring below a specific external norm (e.g. 75 years). Other approaches define premature mortality more selectively, identifying relevant deaths based on specific segments of the age-at-death distribution derived from statistical models (e.g., the constant term in the Makeham 1867 model), or by focusing on particular causes of death (e.g., those considered amenable to medical intervention). In contrast, the capability approach adopted in this study defines premature mortality relative to a threshold age, the justification for which is grounded in philosophical reasoning.

(MALL). The part “minimally adequate” in MALL captures the idea of the threshold in the capability approach. MALL aligns with the concept of a *minimally adequate level of health*, which is a standard level of health which every member of a society should have (Asada, 2006, 2007) and the indicator of a *minimum acceptable standard of a welfare* that separates the poor from the non-poor, i.e., the poverty line (Haughton & Khandker, 2009). Below, we discuss whether MALL should be set specific to the population under study and sex. Next, we introduce and justify our choice of the adult modal age at death in a period life table as the measure of MALL among other candidate measures of MALL from the demographic literature.

2.2.1 Should MALL be Set Specific to the Population in Question?

Similar to the poverty line (Ravallion, 1998), MALL can be specified according to the mortality conditions of a study population (“relative” in the poverty literature) or the mortality conditions of an external reference population (“absolute”) (Anand & Reddy, 2019; Maz-zuco et al., 2021). Since the proposed framework aims to measure lifespan inequity within a population at a specific point in time, we specify MALL according to the mortality conditions of a study population. By doing so, we acknowledge that the distinction between misfortune and injustice changes across places and over time (Shklar, 1990). This decision is consistent with Venkatapuram’s (2013) interpretation of Nussbaum’s list of central capabilities, according to which “different societies will determine the threshold levels of each capability depending on their history and resources” (p.65).

2.2.2 Should MALL be Set Specific to Sex?

Another question is whether MALL should be specified as one threshold for both sexes, or as a separate threshold for men and women. Demographers and epidemiologists often analyze mortality data stratified by sex because of the consistent and marked differences in age-at-death distributions between men and women. When applied to MALL, this common practice of stratification implies that we accept different norms of equity for men and women. If the primary cause of these differences is biology or evolution (thus, sex), then different norms for men and women may be acceptable. If the primary cause of these differences is social (thus, gender), then we need a single norm and a single MALL rather than sex stratification. Differences between men and women result from a complex interaction between biological and social factors, rather than a dominance of one of the effects (e.g., Bird & Rieker, 2008; Luy, 2003; Luy & Gast, 2014; Madigan, 1957; Waldron, 1983; Waldron & Johnston, 1976; Zarulli et al., 2018). It is thus impossible to decide whether the “nature” or “nurture” is the preliminary reason for the differences in the length of life between men and women. In particular, the task of distinguishing the effect of sex and gender on survival becomes more difficult in the recent findings of epigenetic evidence: As demonstrated by Iannuzzi et al. (2023), external factors (i.e., “nurture”) can modulate gene expression via epigenetic mechanisms, thereby shaping how biological differences in survival between the sexes are manifested. The capability approach implies, in principle, the same threshold for men and women across the capabilities. However, due to differences in the maximal potential of both sexes in respect to the length of life (as a result of the “nature”), Anand and Sen (1995) and Sen (1992) suggest differentiating the thresholds for

the length of life by sex. The same argument is used by Anand and Reddy (2019) to reject a single standard for determining life years lost for men and women in the Global Burden of Disease study. Therefore, in this paper, we follow the standard practice of sex stratification in demography and epidemiology. This decision implies that, in quantifying lifespan inequities within a population, we explicitly accept different normative standards of equity for men and women and refrain from assessing whether lifespan inequality between men and women is inequitable.

2.2.3 Measuring MALL

In this section, we examine commonly applied life table statistics, such as central tendency statistics and demographic measures of threshold age as candidate measures of MALL. Specifically, we first introduce the modal age at death and justify its use as the measure of MALL. We then discuss characteristics of other commonly used statistics of central tendency in age-at-death distributions, as well as the life table threshold age, and explain why they are less suitable for measuring the MALL.

In a period life table, the modal age at death represents the most common length of life in the distribution of ages at death. Since the work of Lexis (1877, 1878), the old-age mode has been referred to in demography as the “normal” or “typical” length of life (e.g., Canudas-Romo, 2010; Diaconu et al., 2016; Horiuchi et al., 2013; Kannisto, 2001). Influenced by Quetelet’s (1871, 1848) work, Lexis considered the old-age mode the “true” average and referred to deaths at this age as “lives of full length” (Véron & Rohrbasser, 2003).

As demonstrated by Canudas-Romo (2010) and mathematically proven by Horiuchi et al. (2013), shifts in the modal age at death only occur when improvements in mortality are achieved at ages older than the mode. In other words, if improvements in mortality rates occur at ages below the mode, the mode will not shift to older ages. Conversely, defining the threshold age as the mode implies that MALL increases only when mortality decreases at ages at which death can be considered old-age mortality, i.e., at ages above the mode. Such a shift represents society’s commitment to ensuring its members to enjoy longer lives by targeting health and longevity improvements at older ages, with the new threshold age representing a new definition of the lives of normal length. When mortality decreases at ages below the mode, the mode does not change, but the number of those deprived of the “life of normal length” in the life table cohort as well as the average lifespan deprivation change. This dual property of the modal age at death—that reductions in mortality for ages below this threshold reduce the number of premature deaths and the average lifespan deprivation, while at the same time capturing societal progress towards longer lives as mortality falls for ages above the threshold—makes it a desirable measure for separating premature from non-premature deaths. For this reason, we adopt the modal age at death as the MALL statistic.

Life expectancy is the average length of life in a life table. It is not suitable as a measure of MALL for two reasons. First, the distribution of ages at death is left-skewed, and in such skewed distributions, the mean does not accurately represent the central tendency. The choice of life expectancy as the measure of the normal length of life was already criticized by Jacques Bertillon in 1878 for not indicating “the probability of death”: when mortality at younger ages is high, life expectancy is located “at the ages at which death most rarely occur” (p. 461, as cited in Véron & Rohrbasser, 2003). Second, a decrease in mortality at any age increases life expectancy and therefore raises the MALL when set at life expect-

tancy. For instance, a decline in mortality at age zero could increase life expectancy from 69.9 to 70.5 years. Consequently, a death at age 70 would be considered premature, resulting in a half-year deprivation of lifespan, even if the underlying risk of death at age 70 and above remain unchanged. When mortality at older ages remains constant, reclassifying deaths at those ages as premature solely due to improvements in mortality at younger ages is unjustified because the underlying risk of death at those ages has not changed. This is the second argument against using life expectancy as the threshold for quantifying MALL.

Similarly, percentiles of the distribution are not good candidates to measure MALL. To begin, the choice between specific percentiles is arbitrary, e.g., why choose the median – defined as the age by which 50% of the deaths in the life table occur – rather than another percentile, such as the 49th or 51st? Furthermore, the percentile's location is only affected by changes in mortality below the percentile. As argued in the case of life expectancy, this characteristic is undesirable to measure MALL.

As an alternative to the old age mode, the age that separates premature and non-premature deaths could potentially be defined by another well-established demographic concept: the life table threshold age.³ The life table threshold age was first defined by Zhang and Vaupel (2009) for the inequality of ages at death measured by the e^\dagger statistic. It represents the age below which avoiding deaths reduces inequality in life table ages at death and above which it increases. As with the modal age at death, this property of the threshold age is desirable within a capability-based framework: a decrease in mortality above the threshold age indicates that a population's mortality conditions results in a more unequal distribution of lifespans. Conversely, when the lives of those below the threshold age are prolonged, the distribution becomes more equal. However, the life table threshold age for a lifespan inequality varies depending on which inequality statistic is used (Aburto et al., 2019; Gillespie et al., 2014; Martin et al., 2023; Van Raalte & Caswell, 2013), and each of these statistics carries its own ethical assumptions (Asada, 2007; Harper et al., 2010; King et al., 2010; Kjellsson et al., 2015; Temkin, 1993). MALL should not be dependent on inequality statistics used. Moreover, the ethical assumptions of these statistics with respect to lifespan inequality are necessarily different from those of the capability approach applied in this study and discussed in detail in Sect. 2.1. For these reason, the life table threshold age is not an appropriate measure of MALL.

Taken all considerations discussed above, this study operationalizes premature mortality by MALL, measured with the modal age at death, relative to a specific population and stratified by sex.

2.3 Quantifying Lifespan Inequity

Analogous to the operationalization step of the framework construction discussed in the previous section, the capability approach does not provide comprehensive guidance on the aggregation of deprivation for a lifespan inequity statistic, which is the task of the third, quantification step. However, the capability approach offers two useful insights in the quantification step. First, the capability approach suggests that lifespan inequity arises from the deprivation of years of MALL among those who die prematurely. To quantify the extent of

³ It should be noted that lifetable threshold age is a statistic specifically derived to study characteristics of inequality in the lifetable distribution of ages at death. It quantifies a different concept than the threshold age of premature mortality we are concerned about in this study.

lifespan inequity, however, we must examine the lifespan distribution of the entire life table cohort, not just those who die prematurely. This means that the index must account for the deprivation of those below the poverty line as well as the zero deprivation of those above it. Second, the capability approach suggests that we focus on the years lost due to premature mortality rather than the years lived by those who die prematurely. This means that our measure of lifespan inequity should quantify *shortfalls* rather than *attainments* of life years.⁴

Besides these conceptual insights, the capability approach offers limited guidance on the quantitative measurement of lifespan inequity. Therefore, we turned to poverty studies for methodological insights. The first question to which poverty studies can give guidance is whether to normalize lifespan deprivation with respect to MALL. As discussed in the previous section, we are setting MALL specific to a study population. To enable comparisons of lifespan inequity across different populations, we need to control for differences in MALL thresholds across populations. Following similar approaches used in poverty studies, we thus divide lifespan deprivation by the threshold of MALL. This solution places greater emphasis on inequities in populations with a low MALL: relative deprivation implies that the same absolute deprivation means more in low MALL populations (e.g., 5/60) than in high MALL populations (e.g., 5/90).

The second question to which poverty studies can guide us is how to summarize lifespan deprivation below MALL into a single metric to measure lifespan inequity. Sen (1976) points to three important aspects of poverty to quantify deprivation: the incidence, depth, and distribution of poverty among the poor. Two widely used poverty indices measure these three aspects: the Sen-Shorrocks-Thon (SST) index (Houghton & Khandker, 2009; Sen, 1997; Shorrocks, 1995; Thon, 1979; Xu, 2014) and the measure P_2 from the Foster-Greer-Thorbecke (FGT) class of indices (Foster et al., 1984, 2010). We introduce each of these measures below with respect to measuring lifespan inequity. Both indices take values between 0 and 1, with a smaller value indicating lower level of lifespan inequity.

The SST index for lifespan deprivation is derived as:

$$SST = I \cdot Dep \cdot [1 + G^P] \quad (1)$$

I measures the incidence (also known as *headcount ratio* in poverty studies), which in our case is the *incidence of premature mortality*. It is the proportion of life table cohort whose lives are shorter than the MALL:

$$I = \frac{1}{l(0)} \int_{x=0}^M \rho(x) dx \quad (2)$$

⁴ As shown by Kjellsson et al. (2015), this distinction between shortfalls and attainments is important in comparative studies of inequality. In the case of double-bounded variables, when inequality is measured using a relative measure, as in our case (discussed in the next section), different conclusions about changes in inequality in comparative studies can be drawn depending on whether we measure inequality in shortfalls or inequality in attainments. In our measurement framework, the lifespan of those who die prematurely is such a double bounded variable, with a lower bound of zero years and an upper bound of the MALL. Consequently, a reduction in mortality at any age below the MALL leads to an increase in lifespan (attainment) and a reduction in lifespan deprivation (shortfall) among those whose deaths are postponed as a result of this reduction.

Where $\rho(x)$ denotes number of deaths at age x , M denotes the MALL, which is the modal age at death, and $l(0)$ is the life table radix.

Dep is the *depth of premature mortality*, defined as the average lifespan deprivation among premature deaths. As discussed above, lifespan deprivation is normalized. Analogous to the *depth of poverty* (or *income gap ratio*) in the most common poverty measures (Sen, 1997), it is derived as:

$$Dep = \frac{1}{l(0)} \int_{x=0}^M \left(\frac{M-x}{M} \right) \rho(x) dx \tag{3}$$

where $(M-x)$ is the lifespan deprivation of those who died at age x . Therefore, $\frac{M-x}{M}$ is a relative deprivation for death that occurs at age x with respect to the MALL. $\rho(x)$ denotes number of deaths at age x .

G^P is the *distribution of premature mortality* for the entire population quantified by the Gini coefficient:

$$G^P = \frac{1}{Dep^P} \frac{1}{2l(0)^2} \int_{x=0}^{\omega} \int_{y=0}^{\omega} |g(x) - g(y)| \rho(x) \rho(y) dydx \tag{4}$$

For $z=\{x, y\}$, the lifespan deprivation ratio for death at age z is defined as

$$g(z) = \max\left(0, \frac{M-z}{M}\right),$$

and $Dep^P = I \cdot Dep$ is the depth of premature mortality for the entire life table cohort.

As $Dep^P = I \cdot Dep$ and $G^P = \frac{GMD^P}{Dep^P}$, where GMD^P is the Gini Mean Deviation of lifespan deprivation ratios for the entire life table cohort, Formula (1) can be rewritten as:

$$SST = Dep^P \cdot [1 + G^P] = Dep^P + GMD^P \tag{5}$$

According to formula (5), the lower the average lifespan deprivation in the life table cohort (Dep^P), and/or the more equally it is distributed (GMD^P), the lower the lifespan inequity.

The measure P_2 from the Foster-Greer-Thorbecke (FGT) class of indices (Foster et al., 1984, 2010) also quantifies simultaneously the incidence, depth, and distribution of poverty, as shown by Sen (1997, p.179):

$$FGT = I \cdot [Dep^2 + (1 - Dep)^2 \cdot CV] \tag{6}$$

where is CV is the coefficient of variation in lifespan deprivation among those who die prematurely. Alternative specification of the index directly derived from the formula for this class of indices is:

$$FGT = \frac{1}{l(0)} \int_{x=0}^{\omega} g(x)^2 \rho(x) dx \tag{7}$$

A

$$VAR^P = \frac{1}{l(0)} \int_{x=0}^{\omega} g(x)^2 \rho(x) dx - \left(\frac{1}{l(0)} \int_{x=0}^{\omega} g(x) \rho(x) dx \right)^2 = \frac{1}{l(0)} \int_{x=0}^{\omega} g(x)^2 \rho(x) dx - (Dep^P)^2,$$

where VAR^P is the variance in lifespan deprivation in the life table cohort, formula (7) can be rewritten as:

$$FGT = (Dep^P)^2 + VAR^P \quad (8)$$

Consequently, similar to the SST index, the value of the FFG index depends on both the average level of deprivation and the inequality in its distribution in the life table cohort.

As measures of lifespan inequity, there is no definitive rationale for preferring either the SST or the FGT index. A potential basis for selection could involve examining the properties of the inequality measures embedded within each index—specifically, the Gini mean deviation in the SST (according to formula (5) and the variance in the FGT (formula (8)—from an ethical perspective (Asada, 2007; Sen, 1997; Temkin, 1993). However, the capability approach does not offer guidance as to which set of properties better aligns with its theoretical foundations. Moreover, the extent to which the ethical considerations raised by the capability approach (e.g., which forms of inequality are normatively unacceptable) correspond to the ethical assumptions implicit in standard inequality measures (e.g., who should be compared to whom, or how differences should be aggregated) remains unclear. Given these uncertainties, and the fact that the SST and FGT indices produced similar empirical results, we present the main findings based on the SST analysis in the Results section, with corresponding results from the FGT analysis provided in the online supplementary material, file 2.

3 Empirical Application

In the empirical application of the proposed framework for measuring lifespan inequity, we focus on the United States from 1933 to 2020, and compare the results with those for other high-income countries. We report the SST index findings and robustness checks in the main text below and include the FGT index results in the online supplementary material. We discuss how differences in the three elements of the index (incidence, depth, and distribution) contribute to the overall SST index in the United States over the study period and how they contribute to changes in the index over time. We also discuss the differences between the SST index in the United States and in other countries in selected years.

3.1 Data and Methods

The following high-income countries, which are commonly used as comparator countries to study the unfavourable trends in US life expectancy (e.g., Crimmins & Beltrán-Sánchez, 2011; Harper et al., 2021; Ho, 2022; Ho & Henci, 2018; Verguet & Jamison, 2013), are used in this study: Australia, Austria, Belgium, Canada, Denmark, Finland, France, Italy, Japan, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, and United Kingdom. These countries, along with the United States, have maintained high levels of economic development over several decades, experienced mortality transitions in a similar time frame, and

possess population sizes conducive to generating reliable estimates. We compare MALL and lifespan inequity in the United States and the other high-income countries from 1933 to 2021. These years mark the years the US mortality data is available in the Human Mortality Database (HMD, 2024) at the time of the writing of this paper. The few missing observation points in the HMD (2024) are for Austria (1933–1946 and 2020–2021), Japan (1933–1947), and Portugal (1933–1939). In reporting the results of the study, we acknowledge the fact that the results of the comparative part of the study for the years 1933–1947 may be biased as a result of these omissions. Therefore, we do not include information on the average gap between the US statistics and those of other countries in 1933 in the relevant table. We do include the individual country scores for this period in the figures, however, as we found these years to be still informative for the study. Moreover, these missing data do not affect the informative part on the development of the phenomena in the US. We use deaths, population exposures, and life tables in single-year age groups.

Deaths in individual age groups are subject to random fluctuation. It is therefore difficult to select a single age at which most deaths occur in the life table cohort. The modal age at death is also difficult to identify when the age-at-death distribution is flat over numerous ages or when two adult peaks are observed. However, these challenges can usually be overcome by first smoothing the mortality data, either parametrically (Cheung et al., 2005) or nonparametrically, as is done in this paper. Following Diaconu et al. (2020, 2016), Horiuchi et al. (2013), and Ouellette and Bourbeau (2011), we first smooth the mortality hazard with P-splines and then locate the modal age at death from the resulting death density (Camarda, 2012; Eilers & Marx, 1996). This method of estimating modal age at death was originally proposed by Ouellette and Bourbeau (2011). It allows the modal age at death to be derived with precision and free from any additional assumption about the distribution of ages at death. As recommended by Horiuchi et al. (2013), the smoothing procedure for estimating modal age at death is limited to ages 10–100. We use functions from the *MortalitySmooth* package in R (Camarda, 2012).

We used the Shapley decomposition method (Aristondo, 2023; Aristondo & Onaindia, 2020; Shapley, 1953) to derive the decomposition of changes in the SST index in the United States and the differences between the SST index value in the United States and that of other study countries.

3.2 Results

In discussing the results of the empirical study, we focus on the question concerning the level and trend of the threshold age for premature mortality (i.e., Minimum Adequate Length of Life, MALL) (Fig. 1; Table 2) and lifespan inequity (Fig. 3; Table 2) in the United States over the period 1933–2021. We discuss in detail the contribution of the three components of the lifespan inequity index to the observed change in lifespan inequity index of the SST (Table 1). Additionally, the results for the relative position of the United States in the MALL are contrasted with those for life expectancy, the most commonly applied statistic in comparative studies of mortality (Fig. 2). We contrast trends of MALL and SST over time in the United States to other high-income countries (Figs. 1 and 3; Table 3). In the online supplementary material file 1, we include Figs. – A, which show trends in the three elements of the SST index in the individual study countries over the period 1933–2021. The results

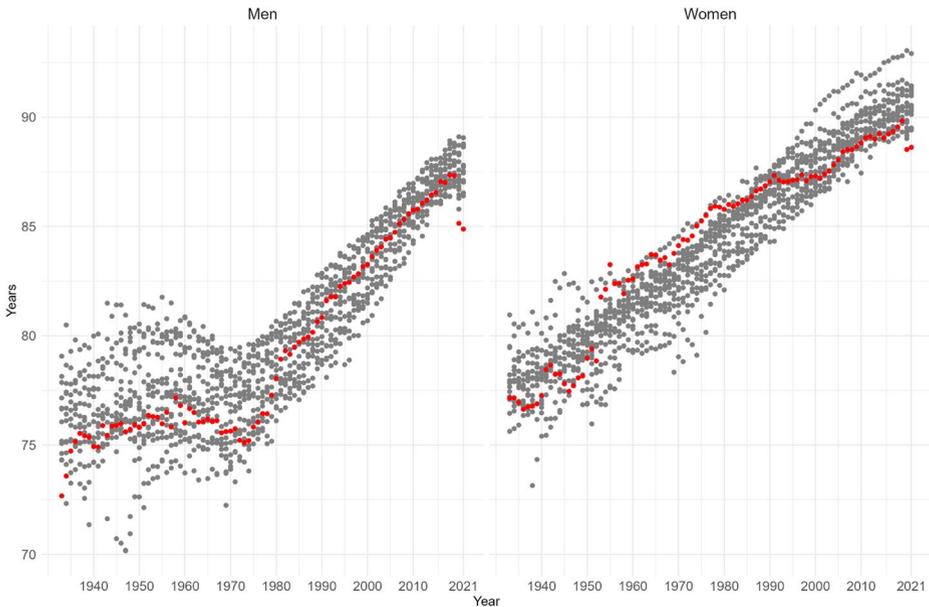


Fig. 1 Minimum Adequate Length of Life in the United States (red) and selected high-income countries (grey) by sex, 1933–2021 Notes: Other countries are: Australia, Austria (1947–2019), Belgium, Canada, Denmark, Finland, France, Italy, Japan (1947–2021), the Netherlands, Norway, Portugal (1940–2021), Spain, Sweden, Switzerland, and the United Kingdom. Data source: Human Mortality Database (2024)

for the years of the COVID-19 are discussed at the end of this section, separately from the overall trends.

Between 1933 and 1950, American men and women had a lower MALL than most of the other high-income countries (Fig. 1; Table 3). Since 1951, the trend of the MALL has been different for men and women in the United States, and thus the resulting gap in the MALL between the United States and other countries differed between the sex.

As compared to other countries, conditions for American men's premature mortality remained particularly unfavorable until mid-1970, when the MALL began again to increase (see also, Table 1). From mid-1980 and until mid-2010, the MALL for American men remained at the average level of the study group of countries, indicating, on average, no particular disadvantage of American men among the study countries with respect to the premature mortality threshold.

At the same time, American women, experienced a tremendous increase in the MALL of 2.9 years at the beginning of 1950s, making them the leading country until 1991. This development was followed by 10 years of no improvement in the MALL, which caused American women to move from the position of having the highest threshold age of fair length of life to that of lagging behind other high-income countries, beginning in 2005 and continuing until the end of the study period.

The comparative study of the trend in the age threshold for premature mortality in the United States presents not only a different aspect of the mortality disadvantage of its population compared with other high-income countries than the comparative study of life expectancy (LE; Fig. 2), but also the statistics show a different trend: While the LE in the United

Table 2 Minimum adequate length of life (MALL), the Sen-Shorrocks-Thon (SST) index of lifespan inequity And its components in the United States, by sex, in selected years 1933–2021. Decomposition of the SST and change in the SST

Year	Components of the SST				Relative Contribution to the SST (in %)				Relative Contribution to Change (in %)			
	MALL	SST	I	Dep	G ^P	I	Dep	I+G ^P	SST	I	Dep	I+G ^P
Men												
1933	72.7	0.38	0.65	0.35	0.67	9	-99	190	-	-	-	-
1950	75.8	0.29	0.66	0.26	0.67	21	-164	244	-0.091	3	-103	0
1970	75.6	0.26	0.64	0.24	0.68	20	-190	271	-0.030	-25	-80	5
1990	80.8	0.23	0.66	0.21	0.66	32	-225	293	-0.024	32	-122	-11
2010	85.7	0.22	0.69	0.19	0.65	48	-259	311	-0.016	63	-152	-11
2019	87.3	0.23	0.73	0.19	0.63	58	-248	290	0.015	91	27	-18
2021	84.9	0.25	0.70	0.22	0.63	43	-212	269	0.018	-57	158	-2
Women												
1933	77.2	0.36	0.70	0.31	0.66	24	-122	198	-	-	-	-
1950	79.0	0.24	0.60	0.23	0.72	8	-206	298	-0.123	-38	-70	8
1970	84.1	0.23	0.70	0.19	0.67	47	-249	302	-0.009	398	-427	-71
1990	87.0	0.19	0.69	0.17	0.66	56	-303	347	-0.033	-6	-92	-2
2010	88.8	0.18	0.67	0.16	0.67	51	-327	376	-0.016	-44	-58	3
2019	89.8	0.18	0.68	0.16	0.66	56	-320	364	0.005	74	38	-13
2021	88.6	0.20	0.70	0.18	0.65	55	-287	332	0.018	23	84	-7

The SST index is defined as the product of three components: incidence of premature mortality (I), depth of premature mortality (Dep), and the distribution of premature mortality measured by the Gini Coefficient (I+G^P) (See Formula (1)). The relative marginal contribution to of the three components to SST and the relative contribution of the three components to change in SST was derived with the Shapley decomposition method. The relative contribution to the SST level is computed by dividing each component's marginal contribution by the SST value. Similarly, the relative contribution to the change in the SST is calculated by dividing each component's contribution by the absolute magnitude of the SST change

Data source: Human Mortality Database (2024)

States for both sexes has consistently been at the lower end of the study group of countries, the comparative position of men with respect to the MALL has been in the middle of the group since the 1980s, And American women were at the top of the group with respect to the MALL between the late 1950s And the 1980s, with an average advantage of 1–2 years.

In 1933, the lifespan inequity index of SST in the United States was lower than in most other high-income countries (Fig. 3). The first sub-period, from 1933 to mid-1950, is characterized by the fastest decline in the US inequity (Table 2). In the decades that followed, until the early 1980s, the rate of decline in lifespan inequity in the United States was much smaller than in other countries, resulting in a growing comparative disadvantage of the US lifespan inequity (Table 3). Despite continued declines in other high-income countries (until the COVID-19 pandemic, where all countries experienced an increase), lifespan inequity increased in the United States since the early 2010s. As a result of these unfavorable developments in the United States, the country has had the highest lifespan inequity among the countries studied since the late 1980s for men And since the late 1970s for women, And already the second highest since the 1960s (after Portugal). In 2021, the average difference between the United States and other countries in the SST index equaled 30% for men And 31% for women compared to the corresponding US index.

Of the three components of the SST index in the United States, i.e., incidence (I), depth (Dep) and distribution of lifespan deprivation ($1+G^P$), the distribution component had the largest positive marginal contribution to overall inequity (Table 2). However, this component contributed the least to the observed changes in the SST in the United States during the study years. The marginal contribution of the incidence in premature mortality was also positive but small. The value of I was a subject to fluctuations between 60% And 73% of deaths in the United States being premature. The depth of premature mortality is the component with the negative marginal contribution to the value of SST index, which means that it decreased the value of the index. At the same time, Dep contributed most to the decline in the index between the study years up to 2010. On average, Dep is also the largest contributing component to the SST gap between the United States and the remaining high-income countries (Table 3). With the exception of 1950, the average marginal contribution of the other two components of the SST, I and distribution of lifespan deprivation, to the gap between the United States and other countries was small. Moreover, the contribution of the distribution of lifespan deprivation was negative, indicating that, on average, this component led to a worse value of the inequity index in other countries compared to the United States.

Already in 2019, MALL was lower and the SST lifespan inequity index was higher in the United States than in other countries. The COVID-19 pandemic lowered the US premature mortality threshold by 2.4 years for men and 1.2 years for women in 2019–2021. As a result, in 2020 and 2021, MALL for both men and women in the United States was similar to its level in the late 2000s and much lower than in the other countries studied, on average by 2.9 years for men and 2 years for women. It should be noted that the decrease in LE in the United States due to the pandemic was even greater: by 2.8 years for men and 2.1 years for women. It also caused an increase in the lifespan inequity index of the SST due to an increase in the depth of premature mortality for both sexes. The changes in the lifespan inequity due to the pandemic had a much larger effect on the SST in the United States than in the other countries, mainly due to a larger increase in the Dep, therefore leading to an increase in the average gap in lifespan inequity between the United States and the other countries.

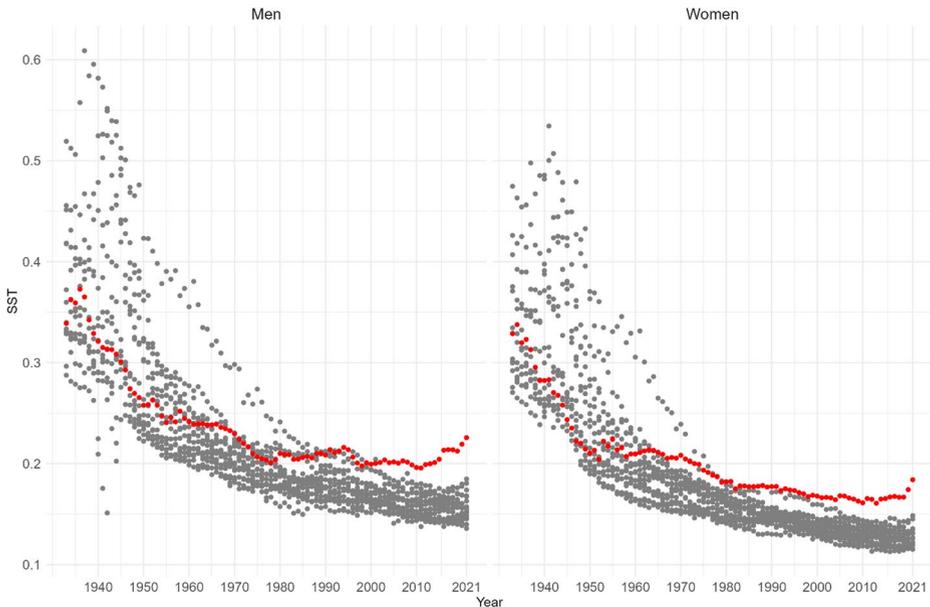


Fig. 3 Sen-Shorrock-Thon life span inequity in the United States (red) and selected high-income countries (grey) by sex, 1933–2021. Notes: Other countries are: Australia, Austria (1947–2019), Belgium, Canada, Denmark, Finland, France, Italy, Japan (1947–2021), the Netherlands, Norway, Portugal (1940–2021), Spain, Sweden, Switzerland, and the United Kingdom. Data source: Human Mortality Database (2024)

4 Summary and Discussion

In this paper, we developed a comprehensive framework for defining and measuring life span inequity, following three steps for building a framework for measuring health inequity. In the definition step, we chose to use the capability approach as the normative basis. The dimension of inequity that our framework focuses on is the first of Martha Nussbaum's (2000, 2011) central capabilities, a normal length of life, which is critical for the equal standing of individuals. In the operationalization step of building the framework, we defined life span inequity as the inequality between individuals in a life table cohort resulting from the deprivation of life span due to premature mortality. Period life table represents mortality conditions of a population under study. To our knowledge it is the first time that life span inequity has been defined in this way. We identified premature mortality as deaths occurring below a threshold age, which we termed Minimum Adequate Life (MALL), in analogy to poverty studies. In the quantification step, drawing from poverty studies, we proposed to quantify life span inequity by adapting a commonly applied poverty measures that simultaneously quantify life span deprivation in terms of three statistics: incidence, depth, and distribution.

To demonstrate the utility of this approach, we empirically applied this framework to quantify life span inequity in the United States and compared its level and trends with those in selected high-income countries. The analysis, based on data from 1933 to 2021, found that the United States initially exhibited a faster decline in life span inequity than other countries, narrowing the gap until the mid-20th century. However, from the 1980s onward,

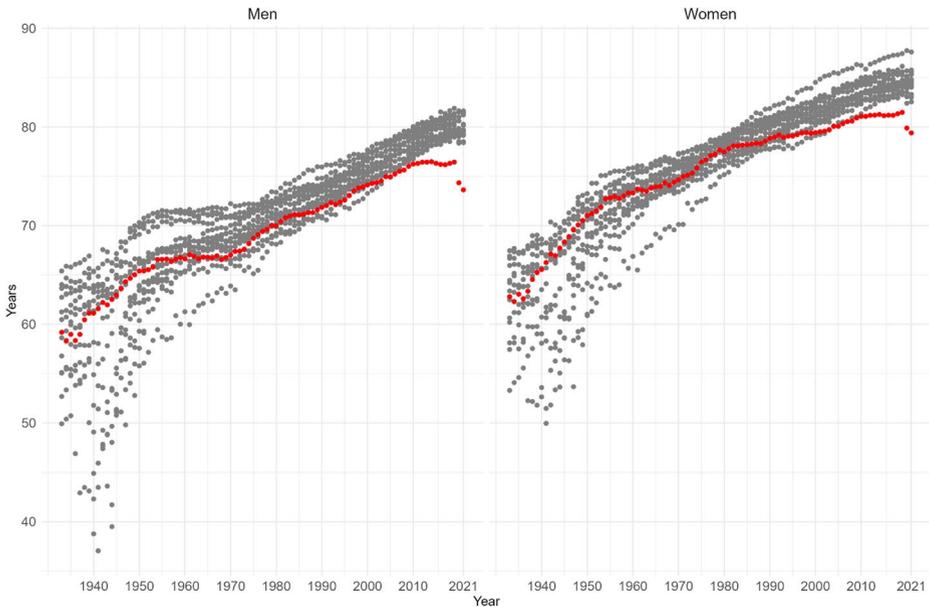


Fig. 2 Life expectancy in the United States (red) and selected high-income countries (grey) by sex, 1933–2021. Notes: Other countries are: Australia, Austria (1947–2019), Belgium, Canada, Denmark, Finland, France, Italy, Japan (1947–2021), the Netherlands, Norway, Portugal (1940–2021), Spain, Sweden, Switzerland, and the United Kingdom (2024). Data source: Human Mortality Database (2024)

the rate of decline in the US stagnated relative to continued improvements in other countries, resulting in the highest levels of lifespan inequity for both sexes by the 2010s. The US disadvantage was primarily driven by the depth of premature mortality, the component contributing most to the difference with other nations. Moreover, the analysis highlighted distinct trends in the US threshold age for premature mortality (MALL), with American men consistently ranking near the study average since the 1980s, while American women transitioned from leading in the 1950–1980s to lagging significantly by 2005. The COVID-19 pandemic exacerbated these differences, lowering the US MALL by over two years and sharply increasing lifespan inequity due to a rise in premature mortality depth, with the effects more pronounced in the United States than in other high-income countries. In short, the United States has a lower MALL and higher lifespan inequity than other high-income countries. Our study confirms previous findings that U.S. longevity increased through the mid-20th century, but began falling behind other high-income countries in the late 1970s/early 1980s. The gap widened thereafter. Persistent or rising mortality among those aged 15–64, compared to continuous improvements in other high-income countries, as well as gains concentrated later in life, has produced both lower life expectancy and greater lifespan inequality (Crimmins, 2025; Gillespie et al., 2014; Harris et al., 2021; Ho, 2022; Ho & Preston, 2010; Verguet & Jamison, 2013; Woolf & Aron, 2018). Mortality stagnation and reversals among working-age adults have been driven by external causes, such as drug overdoses, suicides, and other injuries; metabolic and cardiometabolic conditions; and a slowdown in the improvement of cardiovascular mortality, which became especially apparent after 2010 (Crimmins, 2025; Ho, 2022; Woolf & Schoemaker, 2019). These excess deaths in middle

Table 3 Minimum adequate length of life (MALL), Sen-Shorrocks-Thon (SST) index of lifespan inequity theUnitedI States And average in the selected countries by sex, in selected years 1950–2021. Average difference in the statistics (MALL and SST) between the united States and other countries. Contribution of the three components of the SST statistic to the difference in SST

Year	USA		Other		Difference (USA – Other)		Average SST Difference and Average Percentage Contribution of Three Components to the Difference (in %)			
	MALL	SST	MALL	SST	MALL	SST	SST	I	Dep	1+ G ^P
Men										
1950	75.8	0.287	76.9	0.318	-1.1	-0.031	-11	-43	-56	-1
1970	75.6	0.257	76.6	0.233	-1.0	0.024	9	-4	113	-10
1990	80.8	0.233	80.8	0.203	0.0	0.030	13	0	104	-3
2010	85.7	0.217	85.7	0.176	0.0	0.041	19	12	93	-4
2019	87.3	0.231	87.8	0.171	-0.5	0.060	26	20	85	-5
2021	84.9	0.250	87.7	0.174	-2.9	0.076	30	1	103	-3
Women										
1950	79.0	0.236	79.4	0.275	-0.4	-0.039	-17	-60	-46	5
1970	84.1	0.227	82.4	0.196	1.7	0.032	14	43	70	-13
1990	87.0	0.195	86.2	0.164	0.8	0.031	16	34	74	-8
2010	88.8	0.179	89.5	0.144	-0.7	0.035	20	2	103	-5
2019	89.8	0.184	90.6	0.139	-0.8	0.046	25	10	95	-5
2021	88.6	0.203	90.6	0.141	-2.0	0.062	31	12	93	-5

The relative difference in SST was derived with respect to the US value. The SST index is defined as the product of three components: incidence of premature mortality (I), depth of premature mortality (Dep), and the distribution of premature mortality measured by the Gini Coefficient (1+G^P) (See Formula (1)). The contribution to difference in SST of the three components was derived with the Shapley decomposition method. The relative contribution of each component to the difference in SST is computed by dividing its respective contribution by the absolute value of the SST difference

Other countries are: Australia, Austria, Belgium, Canada, Denmark, Finland, France, West Germany, Italy, Japan, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, and the United Kingdom. The statistics start in 1950 as until 1947 the data is not available for all countries

Data source: Human Mortality Database (2024)

age, often referred to as “deaths of despair,” increased most among less-educated adults and in certain regions, particularly in the Midwest and South (Case & Deaton, 2015,2017; Woolf, 2023). In addition to the causes of death, the structural and policy contexts of limited social protection, gaps in healthcare access, adverse living and working conditions, and broader socioeconomic disadvantage are repeatedly implicated in the shortfall and its geographic concentration in the US (Crimmins, 2025; Krieger et al., 2008; Remington, 2023; Woolf, 2023; Woolf & Aron, 2018). Using an ethically informed framework, our empirical findings, unlike other demographic studies of premature mortality and lifespan inequality, clearly speak to an unjust, ethically problematic phenomenon in the American society. The ethically transparent measurement framework we developed in this study allowed us to make these ethical conclusions.

The development of this framework involved important normative choices. We have clarified and justified our choices, but our use of the capability approach merits additional brief discussion here. We used the capability approach to justify our view that the unequal position of individuals in terms of length of life, specifically, lifespan deprivation due to premature mortality, is ethically problematic, i.e., inequitable. The capability approach

is unusual in its focus on a threshold to define what is ethically problematic, regardless of causes (Asada, 2007). The capability approach does not ask why someone is below a threshold, which in our context is a question about the social, biomedical, behavioral, and environmental determinants of a premature death. Consider, for example, a death below MALL due to a rare genetic condition that is distributed randomly in the population and that current medicine cannot prevent, treat, or cure. According to the capability approach, such a death is unjust because it occurred at an age below MALL. Many other egalitarian⁵ views consider causes of death, but they differ regarding which causes are ethically problematic. For example, if one takes the view, as many public health researchers do (Sørheim et al., 2024; Whitehead, 1991), that justice considerations apply only to avoidable and preventable deaths, then a death from a random genetic disease with no prevention or cure would not count as an unfair death. The underlying assumption of this view is that inequalities of natural (as opposed to social) origin are of no concern to justice. However, if one holds that inequalities due to factors beyond individual control are unjust, often referred to as luck egalitarianism or equality of opportunity (Roemer, 1993), then such a death would count as an unfair death. The purpose of this paper is not to show the capability approach as the most promising view among many egalitarian views but rather to demonstrate the versatility of the well-established capability approach in providing a basis for empirical analysis of lifespan inequality from an ethical perspective. Nevertheless, it is important to recognize that the capability approach considers unavoidable and non-preventable deaths below MALL to be unjust deaths and, accordingly, the level of inequity estimated using our framework would never be zero.

The proposed framework is based on subjective decisions, which are an inherent part of any empirical research (Longino, 1990). Other frameworks could be developed based on a different ethical theory, and future work may involve different operationalization and quantification choices. Since each decision is integral to the framework, any changes would result in a different framework. While our decisions are necessarily subjective, they are grounded in ethical theory, theoretically justified, and transparently communicated. Furthermore, the validity of the framework is specific to the conceptual and empirical context in which its assumptions hold. For example, if the old-age mode cannot be identified, researchers may propose a different measure for MALL, resulting in a distinct framework. The main methodological contributions of this paper are the demonstration of the utility of ethical theory in demographic research and the transparent translation of theory into quantitative measurement.

In conclusion, our framework provides a robust basis for understanding and quantifying lifespan inequity, with the concept of MALL, a threshold age of premature mortality. It provides a valuable tool for assessing the ethical dimension of lifespan inequalities and, thus, serves as a critical step in understanding and addressing inequalities in the length of life within populations explicitly from an ethical perspective. In this paper we have shown that demography needs philosophy to understand and interpret the results of demographic

⁵ Although we characterize the capability approach as an egalitarian theory, this characterization is debated in the literature. Those who do not consider the capability approach as an egalitarian theory focus on the distributional aspect: the capability approach is a sufficientarian view, not an egalitarian view, because the capability approach is only concerned about the distribution below a threshold level. Those who consider the capability approach as an egalitarian theory focus on the relational aspect: the capability approach is primarily concerned about equal standing of persons, which is an important consideration for egalitarians (Kaufman 2006).

models. By simplifying reality through assumptions about the data and their mathematical representation, mathematical models of population processes are necessarily linked to philosophical concepts in order to justify decisions about each of the model specifications. In other words, “demography needs all the theory it can get if it is to be a science and not just a branch of applied statistics” (Burch, 2018, p.126).

Supplementary Information The online version contains supplementary material available at <https://doi.org/10.1007/s11205-025-03711-w>.

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Data Availability The data used in this article is freely available upon registration at the Human Mortality Database at www.mortality.org or www.humanmortality.de.

Declarations

Conflict of interest The authors declare no conflict of interest.

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