How to measure premature mortality? 
A proposal combining “relative” and “absolute” approaches

Abstract
The concept of “premature mortality” is at the heart of many national and global health measurement and benchmarking efforts. However, despite the intuitive appeal of its underlying concept, it is far from obvious how to best operationalise it. The previous work offers at least two basic approaches: an absolute and a relative one. The former – and far more widely used – sets a unique age threshold (e.g. 65 years), below which deaths are defined as premature. The relative approach derives the share of premature deaths from the country–specific age distribution of deaths in the country of interest. The biggest disadvantage of the absolute approach is that of using a unique, arbitrary threshold for different mortality patterns, while the main disadvantage of the relative approach is that its estimate of premature mortality strongly depends on how the senescent deaths distribution is defined in each country. Here, we propose to overcome some of the downsides of the existing approaches, by combining features of both, using a hierarchical model, in which senescent deaths distribution is held constant for each country as a pivotal quantity and the premature mortality distribution is allowed to vary across countries. In this way, premature mortality estimates become more comparable across countries with similar characteristics.

Keywords: premature mortality; mixture model; hierarchichal model

1 Introduction
“Premature mortality” is a highly popular metric of population health, widely used e.g. for the purpose of international and country-level performance assessments interested in capturing some dimension of an “unnecessary” burden of mortality. It features prominently, for instance, as a target of Sustainable Development Goal 3 (“Ensure healthy lives and promote wellbeing for all at all ages”)\(^1\). However, while the concept is intuitively convincing, premature mortality is hard to measure unambiguously, given its latent nature. In practice, several different measures of premature mortality are in circulation. For example, the OECD measures premature mortality in terms of potential years of life lost (PYLL) before the age 70 \([2]\). The WHO considers an age-standardised overall mortality rate from age 30 to under 70 years \([3]\), while Eurostat favours an age-standardized rate below age 65 \([4]\). In the demographic literature, a substantively different, more “endogenous” approach is

\(^1\)The health target 3.4 is about reducing, by 2030, by one third the premature mortality from non-communicable diseases through prevention and treatment and promote mental health and well-being \([1]\).
used, distinguishing a distribution of “natural” deaths from that of premature ones, as first suggested by Lexis [5], and more recently considered by Kannisto [6, 7] and Cheung et al [8]. In this perspective, there is no exogenous age threshold, but only two – partially overlapping – curves of mortality. These two fundamentally different approaches in defining and measuring premature mortality may be referred to as “absolute” and “relative” approaches. While the “absolute” approach uses a fixed age threshold to distinguish between “premature” and “senescent” deaths, the “relative” approach does not define any age threshold, but derives premature mortality on the basis of the age distribution of deaths.

The advantage (and likely appeal) of the “absolute” approach is in its straightforward implementation and interpretation, once the decision on the age threshold is taken. Yet, it is far from clear how the age threshold should be selected, and – more importantly – the choice of specific threshold may critically determine how countries compare against each other in terms of premature mortality. By contrast, the “relative” approach does not suffer from the challenge of setting an arbitrary age threshold, though at the cost of a more difficult interpretation of what a “mature” or “normal” death, as defined by Lexis [5], really means. Moreover, cross-country comparisons are difficult to implement, since the extent of premature mortality depends on the senescent mortality, which substantially varies across countries.

In this paper, we acknowledge that both approaches have strengths and weaknesses, leading us to propose a third way, which may be considered as a constructive compromise between the two.

2 Premature Mortality: An absolute view

The “absolute approach” to measuring premature mortality is the method used by major international institutions that engage in burden of disease and health system performance measurement [e.g. 3, 9, 10]. This approach involves fixing a certain age threshold, below which every death is defined as “premature”. Unfortunately, there is no clear consensus on what this threshold should be: some use 65 years [11], others 70 years and yet others use 75 years of age [12]. Figure 1 illustrates how changing the threshold might well change the ranking of countries: while in Ireland, the below age 75 and below age 65 death rates are very close to each other, the gap is much greater between the two measures for Portugal. Hence, when using the age 75 threshold, Portugal shows a lower rate of premature deaths than Ireland. This ranking is reversed, if we apply an age 65 threshold. More generally, a fixed cut-off does not take into account the specific features of the overall mortality of a given country: a 65-year threshold might seem inadequate for countries characterized by high life expectancy (e.g. Sweden or Japan), while a 75-year threshold clearly is not suited for countries with a life expectancy close to or below 75 years (e.g. Argentina or Brazil).
Several related to premature mortality concepts are based on fixing an age threshold: “midlife mortality”, for instance, which is sometimes defined as the mortality rate at age 45–54 and has been recently used to show a rising trend in USA [see 13], while Eurostat use also “amenable” and “preventable” deaths [see 9, 10]. In essence, amenable deaths capture those causes of deaths that could have been avoided with adequate treatment, while preventable deaths could have been avoided by improved preventive behaviors or measures (i.e. reduced smoking, healthier diets, screening). A further popular “absolute” measure for premature mortality is the Potential Years of Life Lost (PYLL), calculated by multiplying the number of deaths at each age by the number of potential years remaining for that age. Yet also in this case, an ultimately arbitrary cut-off age has to be selected [14]. A possible choice could be using the average current life expectancy in the given population. However, in a comparative perspective it would be difficult to choose a different threshold for every country. This has led some authors to use a so-called “standard life expectancy” (SLE) [15], i.e. a life expectancy representing the potential maximum life span at a given age. The WHO, for instance, has set SLE at around 91 years for age 0 [15]. Although this procedure seems less arbitrary than others, it remains at least debatable as to whether deaths at ages between 80 and 90 may be considered as truly “premature”, especially in the context of countries with a relatively low average lifespan.

3 Premature Mortality: A relative view

A very different approach to achieve the aim traces back to [5], who suggested that premature mortality could be measured by considering the age distribution of deaths (i.e. the death counts of the life table): according to Lexis, in the absence of premature mortality this distribution should have a symmetric shape. Thus, the last, most right hand part of the curve (from the modal age at death up to the end) can be “unfolded” to the left in order to obtain the hypothetical curve without premature deaths (called “normal deaths” by Lexis). Premature mortality in this sense is then measured as the difference between the actual and the hypothetical curve [see 8]. This may be seen as a “relative” measure as the share of “premature” deaths depends on the whole distribution of deaths by age. Lexis’ idea was further elaborated by [16], who highlighted that the hypothetical \(d_x\) curve is not necessarily symmetric, but may be skewed. Figure 2 shows graphically the difference between the two approaches. More recently, [17] implemented a mixture model following

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Note that in this way premature deaths are not individually identified, but only the total share is calculated.
Pearson’s reasoning. This model is as follows:

\[
f_{M}(x, \xi_M, \omega_M, \lambda_M) = \frac{2}{\omega_M} \phi \left( \frac{x - \xi_M}{\omega_M} \right) \Phi \left( \lambda_M \frac{x - \xi_M}{\omega_M} \right)
\]

Equation (1) defines two distributions: \( f_M \) is the age at death distribution related to old age (henceforth called “senescent” mortality function) and \( f_m \), which is the age-at-death distribution of premature mortality. Note that \( f_m \) and \( f_M \) are defined with two skewed normal distributions, i.e. a generalization of the normal distribution, allowing for skewness [see 18]. These components are then mixed to fit the age distribution of deaths, as follows:

\[
d(x) = \eta \cdot f_I(x) + (1 - \eta) \cdot \alpha \cdot f_m(x, \xi_m, \omega_m, \lambda_m) + (1 - \eta) \cdot (1 - \alpha) \cdot f_M(x, \xi_M, \omega_M, \lambda_M)
\]

The share of premature mortality is given by the estimate of parameter \( \alpha \). The advantage of this approach is that defining an age threshold separating “normal” deaths from premature ones is no longer needed, but premature deaths are defined as the number of deaths that let the real distribution of deaths exceed the hypothetical one, as illustrated in Figure 2.

We call this the “relative” approach, as the premature mortality share also depends on how old-age deaths are distributed: if they are shifted to the right, deaths on the right hand-side of the mode are more likely to be included in the premature deaths distributions. Thus, in the relative approach, the exact operationalization of premature mortality also depends on the pattern of the “senescent” mortality, and every country has its own pattern of “senescent” and premature deaths distributions. In this way, we avoid defining a universal threshold that might be questionable for some countries.

However, if we draw a comparison between, for instance, France and USA, we find a result that may seem surprising (see Figure 3): the share of premature deaths in France is much higher than that of the USA, and increasing in recent years – a result that is at odds with what may be our knowledge about lifespan in these countries.
two countries. France is a high longevity country and recent literature shows that premature mortality has declined and not increased in the last years [19], while it is well-known that the USA has a lower life expectancy and a relatively high level of premature (or mid-life) mortality [13, 20].

The explanation of Figure 3 is that in France the “normal” deaths shifted to the right in the last decades, and this probably produced the increase in the share of premature deaths (i.e. deaths that before were included among the “normal” ones are now deemed as premature). In the USA, instead, the “normal” deaths distribution is located far more to the left, thus encompassing also deaths that in France would be more likely considered as “premature”. Figure 4 shows that, surprisingly, the relative measure defined by (4), suggests an increasing trend of premature mortality. Even more striking is that France is one of the countries showing the sharpest increase of premature mortality in recent years, while the USA share of premature deaths has stabilized somewhat.

Hence, while on the one hand, the relative approach eliminates the difficult choice of the age threshold, allowing for better comparison between countries with different levels of life expectancy, this may come at the cost of producing counter-intuitive results. The explanation of the latter is that with this approach, the share of premature deaths depends also on the shape and location of senescent curve ($f_M$). So if $f_M$ has a relatively large variance and low mean (as we observe in the USA), it might be that the “premature” curve is hidden by the senescent one and so underestimated, while in countries where senescent deaths shift to the right and are highly compressed (like in France), the area of premature mortality is isolated and more visible, but probably overestimated.

![Figure 4: Prevalence of premature mortality in selected high-income countries, using the relative approach (source: HMD)](image)

4 Reconciling the absolute and relative approach: a hierarchical model

Both “relative” and “absolute” approaches have revealed some pitfalls that render the comparison of premature mortality difficult across countries. In this section, we present an alternative approach that seeks to combine the positive aspects of either previous approach, while trying to avoid their respective drawbacks. To this end, we propose to group some comparable countries and assume that all of them have the same senescent mortality curve, while the premature mortality curve is allowed to vary across countries. This choice is in line with the idea by Le and Lee [21] who apply the Lee-Carter model to a group of populations, allowing each its own age pattern and level of mortality but imposing shared rates of change by age by adding a common factor. This choice may be justified by the rapid diffusion that innovations in the public health sector can have, leading to a relatively swift diffusion of a longevity improvement in one country to others of the same group. Thus, we similarly assume that countries of the same group should have an equal senescent distribution (the common factor), while the premature curve will be
country–specific. In this way, the premature mortality of each country will be easier to compare, as they all will be the complement of the same senescent function. This will be achieved by constructing a hierarchical model where premature mortality coefficients are allowed to vary across countries, while senescent mortality parameters remain fixed, according the equation\(^3\)

\[
d_j(x) = \alpha_j \cdot f^m_j(x, \mu^m_j, \sigma^m_j, \gamma^m_j) + (1 - \alpha_j) \cdot f^M(x, \mu^M, \sigma^M, \gamma^M).
\]  

(5)

Model (5) is estimated with a Bayesian approach, so prior (and hyper-priors) distributions are defined as follows:

\[
\begin{align*}
\alpha_j & \sim U(0, 0.9) \\
\mu^m_j & \sim \mathcal{N}(60, \sigma^2_{\mu^m})T[-\infty, 75] \\
\sigma^m_j & \sim U(0, 20) \\
\gamma^m_j & \sim \mathcal{N}(0, \sigma^2_{\gamma^m})T[-0.8, 0.995] \\
\mu^M & \sim \mathcal{N}(87, 4) \\
\sigma^M & \sim U(0, 9) \\
\gamma^M & \sim SN(-1, 0.5, 1)T[-0.995, 0.995] \\
\sigma_{\mu^m} & \sim U(0, 2.5) \\
\sigma_{\gamma^m} & \sim U(0, 0.2)
\end{align*}
\]  

(6)

Where \(d_j(x)\) is the distribution of deaths by age \(x\) in the life table of country \(j\). We use life table \(d(x)\) rather observed deaths because the latter are confounded by the age structure of populations, while the former are standardized with respect to age structure. Here infant and child mortality is disregarded so \(d_j(x)\) is the distribution only of deaths above age 5. \(f^m\) and \(f^M\) are two skew-normal probability distribution functions with so-called “centered parametrization” [see 22]. These represent the distribution of premature and senescent deaths, which are mixed with mixture parameter \(\alpha_j\). It can be noted that while parameters of \(f^m\) depends on \(j\), parameters of \(f^M\) do not, which means that we assume that senescent component \((f^M)\) remains fixed across countries, the premature one \((f^m)\) varies across countries.

Results are summarized in Figure 5 and, in addition, the comparison between France and USA is also shown (figure 6), which, in contrast to Figure 3 shows that France has a much lower share of premature mortality compared to the USA. Inspecting the results obtained for all considered countries (see Figure 5) we notice that using this approach, USA premature mortality is much higher than in other countries. Moreover – differently from what was suggested based on absolute and relative measures – it appears that this alternative measure shows a stagnation of premature mortality, which remains at 30% since the beginning of the millennium. A particularly high premature mortality is recorded also in Denmark and (somewhat lower, yet increasing) in the Netherlands. These results are not too surprising: the high prevalence of premature mortality in the USA is in line with what has been shown for simplicity infant mortality component is disregarded and model has been fitted only on death occurring at age 5 and higher.
by Case and Deaton [13, 20]. We also know that Denmark underwent a stagnation of life expectancy [23] between 1980 and 2000 (in particular for women, but also for men), and a similar one was observed in the Netherlands [24]. Thus this hierarchical modelling approach not only provides a “reconciliation” between “relative” and “absolute” approaches, but also provides premature mortality results which leads to shared conclusions researchers developed analyzing the specific countries.

4.1 Composition of groups

An important choice to be made when implementing the hierarchical model is the composition of the group of countries who will share the same “senescent” mortality. In the above application, we created a group characterized by high longevity, although other choices could also have been taken. To extend the application and to illustrate the challenge of creating groups, we have applied the same model to most recent data of Latin American populations taken from LAMBDa database [25]. In this case, groups have been defined by combining countries with (1) a relatively high longevity (Chile, Costa Rica, Cuba, Ecuador, Mexico, Panama), (2) medium longevity (Argentina, Brazil, Chile, Colombia, Dominican Republic, Peru and Venezuela) and (3) lower longevity (El Salvador, Guatemala and Nicaragua). This definition of clusters has also been determined on the basis of the model’s goodness-of-fit to the data: if a country has a mortality profile that is very different from the others in the group, the model would not fit adequately.

In Table 1, we reported also the R-hat statistic [26] for the premature mortality parameter only, and the results confirm a satisfying fit (R-hat statistic with a value around 1 suggest a good mixing of the Markov chain and, therefore a good fit of the model). However, it is possible to change the composition of the groups keeping an adequately goodness of fit. For example, Chile has been included both in the high longevity group and in the medium one: in the former Chile has the highest level of premature mortality (29.5%), according to the hierarchical approach, while in the medium longevity group, it has the lowest (10.7%). This means that although statistical measures of fit can assist in a more data driven rather than subjective group assignment, ultimately there will typically remain an element of subjective discretion that can critically affect a country’s relative “performance”.

Inevitably, belonging to a high longevity country makes it more challenging to keep premature mortality low, as the senescent mortality is shifted further to the right, while belonging to a low longevity group makes it easier. Therefore, there is no single “perfect” composition of possible clusters, and for any country belonging to a group or another will make the difference in terms of premature mortality estimate. Hence, the choice of grouping will require careful reasoning and transparency.
4.2 Choosing reference senescent mortality

Another critical choice is about the reference senescent mortality distribution that is used to define the premature mortality distribution. One possibility is to pool all the countries of a given group together and use this “super-country” as the reference – a sort of average distribution. An alternative could be to choose one country as a reference, for example, the country with the highest life expectancy (or the highest modal age at death). Once again, the choice may be partly guided by the goodness of fit: using an average distribution tends to make it easier to have a good fit also for the lowest longevity country, but, on the other hand, having as a benchmark a real country (e.g. Sweden) senescent mortality distribution would facilitate the interpretation of premature mortality prevalence figures, as the “super-population” senescent mortality might be difficult to conceptualise and communicate. There may, however, be cases, in which the “super-population” serves as a very meaningful concept: for example, if sub-national data are considered (regions or provinces), then pooling them together provides a picture of the entire country, and prevalence of premature mortality can be calculated with respect to the national senescent mortality distribution. Hence, the choice of the right reference may be guided by these considerations.

5 Conclusion

Premature mortality is a latent concept, and as such cannot be truly observed. As we have shown, how the concept is precisely operationalized may well qualitatively affect the results obtained. For instance, a given country may be judged to have done “better” than a different country in terms of one measure of premature mortality, but worse according to another measure. Likewise, in assessing a country’s “progress” in tackling premature mortality over time (e.g. in the context of the SDG progress assessments), that progress may be assessed differently, depending on the exact measure that is employed. As the concept of premature mortality enjoys such (understandable) popularity in international comparisons and benchmarking purposes, it seems critical to use a measure that is as reliable as possible.

Classifying the previously used approaches into “absolute” versus “relative” ones, we point out limitations in either approach. To overcome those, we propose a hybrid approach that draws out useful elements of both the absolute and relative approach. This new approach assumes senescent mortality to be fixed for all the countries considered as sufficiently “homogeneous”, while the premature mortality curve is allowed to vary across countries. It is hybrid, in the sense that it defines premature mortality relative to the benchmark that is chosen, but it is also an absolute measure among those countries that are compared with the same benchmark.

As a result, while our hybrid approach overcomes some of the problems of the previous measures, it is not perfect either – and neither could one expect it to be, in light of the latent nature of the concept. Particularly critical issues pertain to the choice of the group of countries a given country is assigned to. While statistical testing of model fit can aid in those decisions to a degree, there remains an inevitable degree of arbitrariness that, however, can and should be explicitly addressed and made transparent in its application. For example, [27] propose a functional clustering of countries’ age distribution of deaths, offering a data–driven way to create
groups which are maximally homogenous, and this – or other equivalent methods, can be used as a starting point for creating country groups. As far as the choice of benchmark within the groups, conditional to goodness of fit, one solution can be preferred only on the base of the ease of interpretation of results.

Appendix: Results from LAMBdA database

Figure 7: Prevalence of Premature Mortality in some Latin American countries (high longevity group), hierarchical approach (source: LAMBdA)

Figure 8: Prevalence of Premature Mortality in some Latin American countries (medium longevity group), hierarchical approach (source: LAMBdA)

Figure 9: Prevalence of Premature Mortality in some Latin American countries (low longevity group), hierarchical approach (source: LAMBdA)

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Availability of data and materials
The datasets generated and/or analysed during the current study are available in the Human Mortality Database (www.mortality.org) and Latin America Mortality Database (https://www.ssc.wisc.edu/cdha/latinmortality/) repositories.

Ethics approval and consent to participate
Not applicable

Competing interests
The authors declare that they have no competing interests.

Consent for publication
Not applicable

Authors’ contributions
Each author made substantial contributions to the conception of the work, to implementation of method, interpretation of results. Each author contributed to revise previous drafts of this manuscript and approve the submitted version. Moreover each author agrees both to be personally accountable for the author’s own contributions and to ensure that questions related to the accuracy or integrity of any part of the work, even ones in which the author was not personally involved, are appropriately investigated, resolved, and the resolution documented in the literature.

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| Countries                | (relative) | (hierarchical) | (absolute) | Rhat |
|-------------------------|------------|----------------|------------|------|
| **Low longevity countries** |            |                |            |      |
| El Salvador             | 0.228      | 0.335          | 0.0127     | 1    |
| Guatemala               | 0.372      | 0.241          | 0.0101     | 1    |
| Nicaragua               | 0.347      | 0.263          | 0.0104     | 1    |
| **Medium longevity countries** |            |                |            |      |
| Argentina               | 0.170      | 0.257          | 0.0078     | 1.01 |
| Brazil                  | 0.282      | 0.229          | 0.0087     | 1.01 |
| Chile                   | 0.149      | 0.107          | 0.0059     | 1.02 |
| Colombia                | 0.251      | 0.158          | 0.0071     | 1.02 |
| Dom. Republic           | 0.274      | 0.203          | 0.0082     | 1.01 |
| Paraguay                | 0.223      | 0.208          | 0.0078     | 1.01 |
| Peru                    | 0.215      | 0.165          | 0.0073     | 1.01 |
| Venezuela               | 0.300      | 0.226          | 0.0089     | 1.01 |
| Uruguay                 | 0.173      | 0.213          | 0.0075     | 1.02 |
| **High longevity countries** |            |                |            |      |
| Chile                   | 0.149      | 0.295          | 0.0059     | 1.02 |
| Costa Rica              | 0.161      | 0.213          | 0.0057     | 1.02 |
| Cuba                    | 0.123      | 0.268          | 0.0059     | 1.05 |
| Ecuador                 | 0.262      | 0.259          | 0.0073     | 1.02 |
| Mexico                  | 0.237      | 0.326          | 0.0076     | 1.02 |
| Panama                  | 0.208      | 0.226          | 0.0063     | 1.03 |

Table 1: Premature mortality estimates in Latin America countries according to absolute, relative, and hierarchcial approach (source: LAMBdA)

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