Measuring Health Inequality

with

Realization of Potential Life Years

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Abstract

This paper proposes a new method to measure health inequalities that are caused by conditions amenable to policy intervention. The method is built on a technique that can separate avoidable and unavoidable mortality risks, using world mortality data compiled by the World Health Organization for the year 2000. The new method is applied to data from 191 countries to estimate health inequalities between age groups, between gender groups, and between and within countries. It is found that, firstly, even for countries with very high life expectancy at birth, such as Japan, there can still be substantial health inequality across different age groups. Secondly, there is a much larger prevalence of gender inequality against females than against males across countries. Moreover, gender inequality against either sex is more prevalent amongst those in the age group 1 and 15. Thirdly, although countries with higher life expectancy at birth tend to have lower health inequality, there are significant variations in health inequalities across countries with the same life expectancy. The results therefore support the notion of using health inequality as a distinct parameter from the average level of health in assessing the performance of health systems.

Keyword: Mortality risk, life tables, avoidable deaths, length of life, inequality.
JEL Classification: D6, I12

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1. Introduction

In the past 50 years, there has been a substantial improvement in the average level of health as measured by mortality rate in many countries; however, health inequalities at all stages of life had either remained static or widened in the past decades (Acheson 2000). Against this background, the World Health Organization (WHO) has placed the reduction of health inequalities between countries and within countries as one of its priorities, and aims to use health inequality, as opposed to the average level of health, as a distinct parameter to assess the performance of national health systems. This new policy perspective is clearly expressed in the World Health Report 2000:

“[It] is not always satisfactory to protect or improve the average health of the population, if at the same time inequality worsens or remains high because the gain accrues disproportionately to those already enjoying better health. The health system also has the responsibility to try to reduce inequalities by preferentially improving the health of the worse-off, wherever these inequalities are caused by conditions amenable to intervention. The objective of good health is really twofold: the best attainable average level – *goodness* – and the smallest feasible differences among individuals and groups – *fairness*.” (WHO 2000: p.26)

To progress towards reducing health inequality, it is necessary to establish targets that are measurable by specified indicators in order to ensure accountability and to evaluate the effectiveness of policies (Braveman 2000). In fact, it is argued that the absence of comparable measures of health inequality across countries is a major hindrance to giving health inequality a higher priority on the global agenda (Murray, Gakidou & Frenk 2000a). This paper aims to contribute to the development of improved methodology for measuring health inequality. Specifically, the paper proposes a new health inequality measure that
distinguishes between health outcomes that are amenable to intervention and those that are not.

To measure health inequality, we first need an attribute called “health outcome” or “health status” that is unidimensional and measurable on a cardinal scale, much like income or wealth (Wolfson & Rowe 2001). Mortality is easily the most obvious choice for such an attribute. The prominence of mortality as a health indicator is reflected in the fact that it is in the core of all summary measures of population health and is widely used for health policy making and evaluation (Murray, Salomon & Mathers 2000b). For instance, one of the United Nations’ Millennium Development Goals is to reduce by two thirds the mortality rate amongst children under five by 2015. Notwithstanding the common practice, using mortality to measure population health and health inequality is plagued with two problems.

The first problem is that mortality does not include non-fatal health outcomes. Focusing on mortality rate may risk neglecting conditions that primarily cause decrements in function but no deaths (Murray et al. 2000b). As a result, there has been a lot of effort to incorporate non-fatal health outcomes into mortality measures. These efforts result in the development of a large array of more comprehensive health indicators, including health-adjusted life expectancy (HALE), disability-adjusted life years (DALYs), disability-free life expectancy (DFLE), active life-expectancy (ALE), quality-adjusted life expectancy (QALE), years of healthy life (YHL), and healthy life years (HeaLY). Each of these measures has its limitations (Murray et al. 2000b). While the search for a better way to incorporate non-fatal health outcomes into the mortality rate continues, the present study does not look at this issue; instead, it focuses on the second problem of using mortality related data in developing and evaluating health policies and systems.

The second problem is that not all fatal health outcomes have the same welfare implications. Health outcomes, fatal or otherwise, can be attributed at the simplest to three
factors: chance, genes, and resources (broadly defined to include all physical and social factors). It is often argued that health outcomes that are attributed to chance and, to a certain extent, to genes, are not amenable and, thus, should be excluded from the health policy process. However, given the fact that genetic engineering has been advancing rapidly, genetic diseases that are fatal today may well be curable in the future. Also, how to identify a death by chance is not trivial; for instance, improvement in road safety and vehicle mechanical control can reduce the probability of fatal car ‘accidents’. On the other hand, a disease related death may indeed be attributed to the patient’s genetic condition. In summary, there is no satisfactory way to identify which fatal health outcomes are the act of nature and thus should be excluded from welfare measures. This issue is important not only for mortality measures but also for other health measures that incorporate mortality as a core component. Furthermore, to the extent that chance and genes can also attribute to non-fatal health outcomes, how to isolate their effects is a general issue in measuring health status, not just related to mortality based measures.

The second problem is perhaps of even greater importance in measuring health inequality than just measuring the average level of health. Health inequality can be defined as variations of health status within a population. Perfect health equality, if measured by age at death, will be the case when everyone in the population survives till a particular age (i.e. a rectangular survivorship curve). This perfectly equal health outcome is practically unachievable. This is because, even if everyone faces an identical distribution of mortality risks, unless the probability of dying is equal to 100 percent at a single point of age and zero elsewhere, the observed age at death of the population will spread across a range of ages. However, it is known that, for genetic reasons, age is the single most important determinant

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1 This is borrowed from Murray, Gakidou & Frenk (1999), who classify four board attributes to health: chance, gene, environment (broadly defined to include all physical and social factors), and the interaction between gene and environment.
2 There is suggestion that given the boundaries that define voluntary or purely genetic are questionable, they should not be excluded from the estimation of mortality risk (WHO 2001).
of mortality risks. On top of that, there are also natural differences in mortality risks faced by the two genders. Lastly, due to chance or randomness, even persons of identical genetic compositions and access to the same amount of resources can still have different health outcomes. In conclusion, because of the act of nature (via either chance or genes), it is inappropriate to define health equality as identical age at death.

Here we propose to define health equality as the state where everyone in the population can realise his/her own potential life years to the same degree. A key feature of this definition is that due to chance and genetic factors, different people may have different potential lengths of life. Consider two new born babies, one is perfectly healthy at birth and has a life expectancy of 90 years, while the other has a genetic health disease and is expected to live till 55 only. Suppose the first one ends up dying at the age of 72 while the second dying at 44. Although there is 28 years gap between their ages at death, both have lived up to 80 percent of their own potential life years\(^3\) that nature allows; therefore, under the proposed definition of health equity, there is no inequality between the two. In short, under the proposed definition, a society that has achieved health equality does not necessarily (and should not) have an identical age at death for everyone.

If both fatal and non-fatal health outcomes are considered, then potential life years should be measured as the maximum expected length of healthy life a person can attain given the effects of chance and genes. However, due to data limitations, the present paper focuses only on fatal health outcomes and therefore measures potential life years as the maximum expected length of life a person can attain given the effects of chance and genes.

This approach was indeed first suggested by Farr (1885) and since then have been applied in a number of studies using vital statistics, including Woolsey (1981) to US, Uemura (1989) to 32 industrialized countries, and McCracken (2002) to regions within the

\(^3\) The calculation of realization of potential life year here is only an approximation of the one formally proposed in section 3. In particular, the calculation should be based on the life expectancy at death rather at birth.
New South Wales State of Australia. Recently Tang et al. (2006) propose using life tables for 191 countries to construct the mortality profile of this hypothetical reference country. The method is briefly explained below. Details of the method and robustness tests are provided in their study.

The next question is how to operationalize this concept of potential life years and measure health inequality accordingly. Recently Tang, Chin & Rao (2006) use a data envelopment method to separate avoidable morality risks from unavoidable mortality risks for a given population, utilizing the world mortality data published by WHO recently (World Health Organization 2002). Given the state of technology and the maximum amount of resources possibly available in human societies at a point in time, the unavoidable morality can be considered as the result of chance and genes, while avoidable morality the result of insufficient access to resources. The paper uses the distribution of age at death (i.e. the length of life) of the avoidable deaths in a stationary population to construct a number of welfare and inequality measures. Using the distribution of age at death to measure health inequality were first suggested by Le Grand (1987; 1989) and Silber (1982). The approach of Tang et al. (2006) differs from their approach in that their measure excludes unavoidable deaths. However, both approaches have limitations. On the one hand, unavoidable and avoidable deaths have very different welfare implications, and therefore should not be treated equally as in Le Grand and Silber. On the other hand, as already pointed out by Tang et al., for the same total death rate, countries with a higher proportion of unavoidable deaths (i.e. a smaller prevalence of avoidable deaths) are better off. Thus, completely excluding unavoidable deaths from an inequality measure could also cause bias in the outcome. The current paper aims to improve on these two opposing approaches by incorporating both avoidable and unavoidable deaths in defining inequality measures, while treating them.

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4 What is termed avoidable mortality in the present study is also known as unnecessary mortality or excessive mortality in previous studies.
differently. Specifically, the paper develops a new indicator, namely the realization of potential life years (RePLY), to measure health inequality.

The remainder of the paper is organized as follows. Section 2 briefly explains the data envelopment method used to separate avoidable and unavoidable morality risks. Section 3 explains the concept of RePLY and how it can be used to measure health inequality within and between populations. Section 4 reports empirical findings for a number of countries in year 2000. The last section offers some concluding remarks.

2. Reference Distribution of Unavoidable Mortality Risks

2.1 Concept

Mortality risks are not static, they can be reduced by improving resource availability, especially those related to health, nutrition and safety. Hence resource is broadly defined, including financial resources and non-financial resources such as human capital, institutions, environment, and technology. Therefore, a country that can provide better resources to a particular population group will see a lower mortality rate for that group. However, even with the best resources that are feasible at a point in time, some mortality risks cannot be completely eradicated, such as those related to chance and genes. Those risks are considered as unavoidable or natural morality risks. Unavoidable mortality risks are expected to change with age and gender, as well as with time, due to technological progress and environmental changes. Consequently, if we can picture a hypothetical country that has the lowest conditional probability of dying (probability that a person aged $x$ at the last birthday dies during the year) for each age-gender groups amongst all countries, this country can then be considered as being free from avoidable mortality risks for a given state of technology and resources that are available at the time of measurement. This country is labeled “the reference country”.

It is necessary to emphasize here that “unavoidable mortality risk”, like any mortality risk, is a probability and therefore an average measure for a population. As a result, it is entirely possible for an individual to have a mortality risk lower than his counterparts in the reference country.

This approach was indeed first suggested by Farr (1885) and since then have been applied in a number of studies using vital statistics, including Woolsey (1981) to US, Uemura (1989) to 32 industrialized countries, and McCracken (2002) to regions within the New South Wales State of Australia. In Farr (1885) and McCracken (2002), regions with highest socioeconomic status are chosen as the reference group. A shortcoming of this is that a single region is unlikely to have the lowest mortality rate for all age and gender groups. On the contrary, Woolsey (1981) and Uemura (1989) circumvent this problem by constructing the reference distribution of unavoidable mortality risks using data from multiple regions or countries. Amongst all these studies, Uemura (1989) is the only one that use international dataset. However, Uemura’s dataset covers only 32 industrialized countries, whereas Tang et al. (2006) and the present study cover 191 countries, including both developing and developed countries. Covering both developing and developed countries is important as it will be seen below that, some developing countries actually have lower mortality rates for certain age and gender groups than their developed counterparts. The construction of the mortality profile of this hypothetical reference country is briefly explained below. Details of the method and robustness tests are provided in Tang et al. (2006).

2.2 Data Envelopment Method

The mortality distribution of the reference country, by age and gender, is constructed by enveloping the observed mortality distributions of all the countries included in the study. A number of assumptions are made in the process:
(a) avoidable and unavoidable mortality risks are uncorrelated;
(b) mortality risks, avoidable and unavoidable, are age and gender specific, and time
variant; and
(c) unavoidable mortality risks for different age-gender groups at a given point of time
are invariant across countries or communities.

Suppose the conditional probability that a person of age $x$ die before reaching the next
birthday is equal to $q_x$. Therefore, if $q_x$ is plotted against $x$, then $q_X = 1$, i.e., a person must
die at age $X$, for a sufficiently large value of $X$.

In Figure 1, the conditional probabilities of dying for three countries are plotted. The
curves for Countries 1 and 2 do not cross each other. For any given age, the conditional
probability of dying is lower in Country 1 than in Country 2. Therefore, Country 1’s
mortality distribution displays first order stochastic dominance over that of Country 2. This
implies that a person in Country 1 is better off than in Country 2 in terms of longevity. On
the contrary, the curves for Countries 1 and 3 cross each other as indicated. This means that
those of ages below $x$ are better off in Country 1, while those above $x$ are better off in
Country 3. In this case, neither country’s distribution displays first order stochastic
dominance over the other, and it is necessary to examine second order stochastic dominance.
However, if a hypothetical country has the conditional probability of dying plotted against
age equal to the envelopment of Countries 1 and 3 from below, then this country’s
distribution will, by construction, display first order stochastic dominance over all the three
countries. This envelopment concept is used to construct the reference distribution of
unavoidable mortality risks.

Suppose there are $K$ countries (in the present study, $K = 191$). The conditional
probability that a person in country $k$ who survives to age $x$ will die before reaching the next
birthday is denoted by $q_{xk}$. Let $\tilde{q}_x$ be the conditional probability of dying for a person in the reference country who survives to age $x$.

Then, $\tilde{q}_x$ is defined as

$$
\tilde{q}_x = \begin{cases} 
\min \{ q_{xk}, k = 1, 2, \ldots, K \} & x < X \\
1 & x = X 
\end{cases}
$$

(1)

To allow for gender differences in natural mortality risks, the construction of the reference country mortality profile is undertaken separately for females and males. Once the reference country mortality profile is constructed, life expectancy for a person in each age group of the reference country can be calculated based on the probabilities of death given by equation (1) using the standard method in life tables (see Appendix for details). In life tables, life expectancy in country $k$, $e_{xk}$, is defined as the number of years a person is expected to live if one has survived to age $x$.

2.3 Mortality Risks for the Reference Population

The proposed method is applied to the life tables of 191 countries in the year 2000 compiled by WHO (2002). This dataset cover all member countries of WHO and essentially the world population. The use of period life tables is not without its critic. Murray et al. (1999) argue that inequality measures based on life expectancy measures from period life tables are difficult to interpret because the assumption that individuals, through out their life time, will be exposed to currently observed mortality risks, which is highly hypothetical. Alternatively, one can use cohort life tables which allows rising life expectancy for any age group over time, based on projection estimations. A practical problem of cohort life tables is that such data are hard to come-by, especially for a large number of countries. As a result, this paper
focuses on period life tables. Furthermore, the fact that all data are sourced from the WHO can enhance data consistency and quality across countries, as data are collected and prepared by experts in the area.

The mortality risk profile for the male and female populations in the reference country are shown in Table 1 and Table 2, respectively. The second column of the tables indicates the country that has the lowest mortality risk for a given age group among the 191 countries in the dataset and, thus, contributes to the identification of mortality risks associated with the reference country. The data envelopment method has identified a mixture of countries from various regions around the world. Countries contributing to the profile of reference populations are quite different for male and female populations. It therefore vindicates the need to construct gender-based reference mortality risk profiles. Furthermore, the fact that the contributing countries are from different continents indicates that ethnicity and race are not dominant factors in determining unavoidable mortality risks.

3. Realization of Potential Life Years (RePLY)

3.1 Concept

The reference country mortality profile constructed here is used as a benchmark to measure natural (or unavoidable) mortality risks. If a country has as much resources and uses them as effectively as the reference country in reducing avoidable mortality risks, then its mortality risks would be the same as the reference country’s mortality risks. That is, it will have no, or negligible, avoidable mortality risks. However, if the country has inadequate resources or is inefficient in utilizing resources than the reference country, its people will have higher mortality risks than the risks observed in the reference country. The difference between the actual and reference country mortality risks is defined as the avoidable mortality risk. As stated in Section 2, we assume unavoidable mortality risk to be age, gender and time
specific, but invariant across countries. That is, a person of age group \( i \) and gender \( g \) will face the same the level of unavoidable mortality risk irrespective of the country of origin.

For an avoidable death that occurs at age \( x \), the person in concern has not fully realized his/her potential length of life. Should the person have access to the same amount of resources as his/her peers do in the reference country, he/she would be expected to survive till \( \tilde{\varepsilon}_x^g + x \), where \( \tilde{\varepsilon}_x^g \) is the life expectancy at age \( x \) of a same gendered person in the reference country.

Therefore, the person has realized his/her potential life years to a degree equal to \( x/(\tilde{\varepsilon}_x^g + x) \). In contrast, for an unavoidable death that occurs at the same age, it can be argued that the person in concern has received 100 percent of the resources he/she needed to live up to his/her potential length of life that nature permitted (otherwise the person would have died earlier).

Here we define the realization of potential life years (RePLY) as

\[
R_x^g = \begin{cases} 
1 & \text{for unavoidable deaths} \\
\frac{x}{\tilde{\varepsilon}_x^g + x} & \text{for avoidable deaths}
\end{cases} \tag{2}
\]

Essentially we give an unavoidable death a health outcome of unit one regardless the age at death, and an avoidable death a health outcome of \( x/(\tilde{\varepsilon}_x^g + x) \) which is less than one and dependent on the age at death. RePLY can also be interpreted as a normalized age at death using the expected length of life in the reference country as the normalizing factor.

The implication of RePLY to health inequality is worthy of further elaboration. On the one hand, for those who die of unavoidable causes, there is no inequality between them regardless of their differences in age at death. On the other hand, even for those who died at the same age, there is inequality between those died of avoidable causes and those died of unavoidable causes. The overall effect on the health inequality measure of a population
therefore depends on the distribution of avoidable and unavoidable deaths amongst the age groups.

Since unavoidable mortality risks are invariant across countries, the number of unavoidable deaths, $u_{xgk}^g$, can be estimated by

$$u_{xgk}^g = n_{xgk}^g \tilde{q}_{xgk}^g$$  \hspace{1cm} (3)

where $n_{xgk}^g$ is the size of group $xgk$ in the stationary population.

The number of avoidable deaths for the group, $a_{xgk}^g$, is equal to the number of all deaths minus unavoidable deaths:

$$a_{xgk}^g = d_{xgk}^g - u_{xgk}^g = n_{xgk}^g q_{xgk}^g - n_{xgk}^g \tilde{q}_{xgk}^g = d_{xgk}^g (1 - \tilde{q}_{xgk}^g / q_{xgk}^g)$$  \hspace{1cm} (4)

where $d_{xgk}^g$ is the number of deaths of group $xgk$, and $\tilde{q}_{xgk}^g / q_{xgk}^g$ is the probability that an observed death is unavoidable. Therefore, the closer is $q_{xgk}^g$ to $\tilde{q}_{xgk}^g$, the larger is the proportion of unavoidable deaths for a given total number of deaths and, thus, the smaller is the proportion of avoidable deaths.

The stationary population rather than the actual population is used in the above calculations. This is because as age at death covers only a small portion of the population – those who died in the year of survey, the actual population of the deaths may not be a good representation of the whole population, especially those who have survived that particular year. This issue is addressed by using the stationary population. The stationary population of a country is constructed by repeatedly subjecting the population to the same age and gender specific mortality rate profiles as observed in the year of survey until the demographic structure becomes static. At the same time, the number of births for males and female, respectively, is standardized to 100,000. The number of deaths for each age-gender group in the stationary population, by definition, will remain unchanged over time. Therefore, the
population of deaths associated with the stationary population provides the expected number of deaths associated with the population.

For group $xgk$ as a whole, the average RePLY is given by

$$r_{sk}^g = \frac{u_{sk}^g}{d_{sk}^g} \frac{a_{sk}^g}{d_{sk}^g} \left( \frac{x}{\tilde{e}_x^g + x} \right)$$

(5)

Using the definition of $u_{sk}^g$, $a_{sk}^g$ and $d_{sk}^g$, (5) can be rewritten as

$$r_{sk}^g = \frac{\tilde{q}_x^g}{q_{sk}^g} + \left( 1 - \frac{\tilde{q}_x^g}{q_{sk}^g} \right) \left( \frac{x}{\tilde{e}_x^g + x} \right)$$

(6)

which is independent of population sizes.6

The value of average RePLY is bounded between 0 and 1. Since $x / (\tilde{e}_x^g + x)$ is less than one, the average RePLY will attain the maximum value of 1 when $q_{sk}^g = \tilde{q}_{sk}^g$, i.e. all deaths are unavoidable. Furthermore, a higher average RePLY will be resulted if either the prevalence of avoidable deaths is smaller, or those who died of avoidable causes have realized more of their potential life years. Therefore, a higher average RePLY is an unambiguous indicator of higher level of welfare.

For gender $g$ as a group, the average RePLY is equal to

$$r_{k}^g = \sum_x r_{sk}^g (d_{sk}^g / d_k^g)$$

(7)

For country $k$ as a whole, the average RePLY is equal to

$$r_{k} = \sum_g r_{k}^g (d_k^g / d_k) = \sum_g 0.5 r_{k}^g$$

(8)

where $(d_k^g / d_k) = 0.5$ because in the stationary population, the total number of deaths for males and females are both fixed at the level of 100,000.7

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6 Equation (6) can also be interpreted as the expected value of a binary random variable taking values 1 (for unavoidable deaths) and the proportion of life years realised (for avoidable deaths), each value occurring with a probability equal to the weight in the equation.
The average RePLY measures proposed here satisfy the three “desirable properties” of summary measures of population health suggested by Murray et al. (2000b). The three properties are:

(1) summary measures should be comprehensible and feasible to calculate for many populations so they can be used to inform the health policy process;

(2) period specific summary measures only make use of information in a given year to construct the measures so there is no double counting of past events and there is no need to forecast future events; and

(3) summary measures should be additive decomposable into measures of population subgroups so that there is consistency between respective measures for the whole population and population subgroups.

3.2 Inequality and Redistribution

It is well recognized that length of life, unlike income or wealth, can not be redistributed. Similarly, RePLY is not an attribute that can be redistributed directly. However, since RePLY measures the health outcome after controlling for unamenable factors at a given point of time, the values of RePLY across different populations can be used as indicators of the relative amount of health related resources they have received. Nevertheless, when two populations have the same value of RePLY it does not mean that they have received the same absolute amount of health related resources. Rather, it means that they have received the amount of resources that allow them to realize their own potential life years to the same degree. Inequality measures based on RePLY, therefore, indicate the variations of the degree of realization of potential life years within the population. To the extent the degree of realization of potential life years is related to the availability of health related resources to

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7 It is possible to rescale the number of total number of births (and thus deaths) so that the size of the stationary population resembles the size of the actual population. This rescaling is useful when measuring health global inequality.
individuals, inequality in RePLY implies that there could be room to redistribute those resources in order to achieve a more even health outcomes within the population.

It is worth noticing that as RePLY has taken account of the difference between avoidable and unavoidable deaths, RePLY based health outcome measures are in line with the call of WHO for health systems to focus on “the best attainable average level” and “inequalities…caused by conditions amenable to intervention” (reciting the quote from Section 1; Italic added).

3.3 Health Inequality Measures

In the public health literature, health inequality has been conventionally defined as variations of health status between population defined by certain socioeconomic characteristics such as income, education, occupation, race or ethnicity, sex, and geographical locations. However, the WHO life tables only stratify country populations by ages and genders, and thus limit our scope to examine the relationship between health inequality and other socioeconomic characteristics within countries. Despite this limitation, RePLY can still be used to measure health inequalities between age groups, between and within gender groups, and between and within countries. Specifically, as genetic differences between different age groups have been accounted for in the measurement of avoidable mortality risks, measures of RePLY are commensurable across different age groups. Therefore, the difference between the RePLY for different age groups can be used to measure between-group health inequality that is not due to the act of nature. Similarly, as genetic differences between males and females have

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8 Gakidou, Murray & Frenk (2000a) suggest measuring health inequality as variations of health status between individuals within the population, without a prior stratification of the population along some socioeconomic dimensions. After the publication of Gakidou et al. (2000a), there has been hot debate about the merit of measuring inequality based on individuals versus socioeconomic grouping. Braveman, Krieger & Lynch (2000) strongly argue that measuring health inequalities based on socioeconomic grouping provides valuable information on the relationship between health status and social background and should not be abandoned in favor of the individual approach. Also see Braveman, Starfield & Geiger (2001) and Murray (2001) for further elaboration of arguments by both sides.

9 Some countries have published race specific life tables, e.g. Black and White in the United States, Maori and non-Maori in New Zealand.
been controlled for, the difference between their RePLY can be used to measure between-
gender health inequality that is attributable mostly to socioeconomic factors.

If a population is divided into percentiles by income, then we can calculate the income
inequality of the population using the average income and the population size of each
percentile. The only assumption we need to make is that everyone within a percentile earns
the same income. Here we calculate health inequality in a similar fashion. The population in
cconcern is the deaths in a stationary population, and the “income” becomes the “health
outcome” measured by RePLY.

Next, we need to choose the type of inequality measures. Gakidou et al. (2000a)
propose two families of individual based health inequality measures: individual/mean
differences (IMD) and inter-individual differences (IID). However, both IMD and IID can be
applied to group data rather than individual data by assuming that everyone within a specific
group is of the same health status. Therefore, they are also applicable to the group data in the
present study.

Individual-mean-differences (IMD) compare an individual’s health status to the
population mean:

\[ \text{IMD}(\alpha, \beta) = \frac{\sum |z_i - \mu|^\alpha}{n \mu^\beta} \]  

(9)

where \( z_i \) is a measure of health status for individual \( i \), \( \mu \) is the population mean of \( z \), and \( n \) is
the population size. The parameter \( \alpha \) determines the significance attached to individuals
located at the ends of the distribution, compared to those near the mean of the distribution. A
higher value of \( \alpha \) implies that an improvement (or a deterioration) of health status occurring
in the most disadvantaged (or advantaged) groups will have a greater impact on the
inequality measure than the same change occurring in other groups. The parameter $\beta$ determines whether the inequality measure is absolute or relative. The IMD becomes the absolute mean deviation when $\alpha = 1$ and $\beta = 1$, and the variance when $\alpha = 2$ and $\beta = 0$.

Inter-individual-differences (IID) are the sum of all possible pair-wise comparisons in the population:

$$IID(\alpha, \beta) = \frac{\sum_{i,j} |z_i - z_j|^\alpha}{2n^2 \mu^\beta}$$

(10)

where $p$ and $q$ are individual indexes. IID becomes the Gini coefficient when $\alpha = 1$ and $\beta = 1$. Moreover, IID and IMD are identical when $\alpha = 2$.

The choice between IMD and IID, and between the values of $\alpha$ and $\beta$ is a normative issue, depending on the underlying social preference (Gakidou, Frenk & Murray 2000b). In WHO (2000), the equality index of child survival\(^{10}\) is calculated using IID with $\alpha = 3$ and $\beta = 0.5$, which is in turn based on a survey of preferences for measuring health inequality of over one thousand respondents (Gakidou et al. 2000b). In this paper we adopt the Gini coefficient and the WHO index, i.e. IID ($\alpha = 3, \beta = 0.5$), as the main health inequality measures, but we also report the results based on a few other IMD and IID measures as a robustness check.

In the context of the present paper, $z_i$ is given by RePLY, the population size $n$ is equal to the total number of deaths, and population mean $\mu$ is equal to the country average of RePLY. Hence the two inequality measures become

$$IMD(\alpha, \beta)_k = \frac{\sum_i |R_{ik} - r_i|^\mu}{d_k (r_k)^\beta}$$

(11)

\(^{10}\)The equity of child survival index is calculated using the distributions of expected survival time under age 5 years.
where $R_i$ is the RePLY of individual $i$ in country $k$, $d_k$ is the total number of deaths in the stationary population (i.e. 200,000), and $r_k$ is the country average RePLY as defined in (8).

4. Empirical Results

In this section we provide empirical results from the application of the methodology developed in this paper to 191 member countries of the WHO for the year 2000. The basic data drawn from the WHO sources are the period life tables representing mortality risks in these countries. The results presented here are designed to demonstrate the new concept of health inequality proposed in the paper and to assess its performance against more commonly used indicators of welfare.

4.1 Robustness of RePLY as a Health Indicator

Before using RePLY to measure health inequality, it is necessary to first examine if RePLY is a ‘good’ indicator of health status. A simple test is to examine the relationship between RePLY and the most commonly used mortality-based health indicator – life expectancy at birth. A simple regression of the average RePLY (i.e. $r_k$) for 191 countries in 2000 against their life expectancy at birth (i.e. $e_{0,k}$) and a constant term returns the following results

$$r_k = 0.0109 + 0.0120 e_{0,k}; \quad R^2 = 0.9999$$

where the figures in the brackets are the standard error.

The goodness-of-fit (i.e. $R^2$) is essentially equal to one, indicating that the two variables are perfectly linearly correlated. This result is not surprising. This is because life expectancy at birth is a measure of the average health status of the whole population, and
that of the reference country (i.e. $\bar{e}_0$) is a measure of the highest potential average health status other countries can achieve; hence, the ratio of $e_{0,k}$ to $\bar{e}_0$ can be viewed as a measure of the degree to which a country has realized its potential health outcome. Therefore, $r_k$ and $e_{0,k} / \bar{e}_0$ should be very close in values, and a regression of $r_k$ against $e_{0,k}$ should yield a constant term close to zero (relative to the value of $r_k$) and a slope coefficient close to the inverse of $\bar{e}_0$. The value of $\bar{e}_0$ is equal to 82.45, and its inverse is equal to 0.0121. These are highly consistent with the regression results reported above. In fact, as shown in the Appendix, $r_k$ is mathematically a close approximation of $e_{0,k} / \bar{e}_0$. Furthermore, it is found that the same relationship holds for each gender group. In conclusion, average RePLY is a very robust measure of the average level of health status; and it strengthens our confidence in using RePLY to assess the average level of health as well as health inequality in a country.

As there is a strong positive relationship between average RePLY and life expectancy at birth, there is little to be gained from using RePLY to measure the average level of health compared with life expectancy at birth. However, the emphasis of the present study is on health inequality and on equitable distribution of health resources, of which the expected length of life is not a good indicator. This is because the expected length of life for a cohort estimated from period life tables is a function of the mortality risk faced by that cohort as well as all its senior cohorts. Therefore the expected lengths of life of two cohorts contain a lot of common elements that reflect the mortality risks of their senior cohorts, which are not directly related to their own, current socioeconomic conditions. As a result, inequality measures based on the expected length of life cannot provide an indication of the level of inequality between the two cohorts. On the contrary, inequality measured by RePLY does not suffer this problem as differences between different age (or gender) groups are driven mainly by the differences in the mortality rates between those age groups only.
Given the strong correlation between average RePLY and life expectancy at birth, and the relationship between life expectancy at birth and other socioeconomic variables such as income is well known, we do not further analyse average RePLY but proceed to discussing the results on health inequality.

4.2 Health Inequality between Age Groups

Figures 2 and 3 show scatter plots of male and female specific RePLY (i.e. $r_{ix}^g$) against age for selected countries, respectively. There is a common trend that as age increases RePLY generally rises toward the upper bound of one. This is not entirely surprising as persons of an older age must by nature have realized more of their potential life years. However, this general trend is coupled with some oscillation in RePLY across age groups, especially in the case of Japan. Japan’s RePLY for the new born is close to that of the reference country, indicating that the country has a very small proportion of avoidable infant mortality. Nonetheless, Japanese males’ RePLY drops dramatically from with the age 1 onward, and does not return to the level of the infant till age 60. In particular, for the group with ages between 1 and 5, those that die on average realise less than 40 percent of their potential life years. Japanese females also suffer a big drop in RePLY from the age 1 onward, nevertheless, they recover to the level of 0.9 by the age of 10. A policy implication is that much more attention, and possibly more resources of the Japanese health system, may need to be directed to children under age 10. This result in fact reflects the merit of using RePLY as a measure of health inequality in that it brings out the commensurable differences between age and gender groups that may not be easily evidenced due to the veil of natural differences in mortality risks between the groups. For countries which have a high life expectancy at birth (i.e. low overall mortality risks) like Japan, inequality between population subgroups can go unnoticed particularly easily.
The US and China provide an interesting comparative study. Infants in the US have a much higher RePLY than their Chinese counterparts. However, the RePLY gap narrows rapidly with age. By the age of 15, the males in the US and China are virtually of the same level of RePLY, whereas the females from the US maintain a substantial lead from their Chinese counterparts till the age of 30 and continues to maintain a small lead afterward. This phenomenon reflects the high avoidable mortality rates experienced by male youth in the United States.

4.3 Health Inequality between Genders

Figure 4 is a scatter plot of the ratio of male RePLY to female RePLY (i.e. \( r_{ik}^m / r_{ik}^f \)) against age. If the ratio is equal to one, it means there is no gender inequality; if the ratio is greater (smaller) than one, it means there is gender bias against females (males). It can be seen that for all age groups, there are consistent bias against females in China, India and South Africa. Amongst the three, the gender bias in China is the highest for infants, with an astonishing figure of close to 1.6 (i.e. baby boys have a 60% higher RePLY than baby girls). The result is believed to be related to the fact that, under the one-child policy and the influence of the social preference for boys over girls, many baby girls are intentionally scarified. Since RePLY will tend to one as age increases, it is expected that the ratio of gender specific RePLY will also tend to one as age rises. However, for these three countries, gender bias seems to be very persistent up to age 40.

The US has a relatively modest gender bias, with the exception that male teenagers in the US with age 10 to 15 being much better off than their female counterparts. The figures for Japan and Russia paint a very different picture in that for many subgroups below age 50, males are worse off than their female counterparts. This phenomenon is believed to be
related to the high suicide rate among young Japanese males and the high impact of alcohol abuse and violence on Russian males.

Gender bias against females, as expected, is much more prevalent than gender bias against males. For the total of 4,202 age groups of 191 countries considered in this paper, the average value of $r_{ik}^m / r_{ik}^f$ is equal to 1.06. However, amongst the 4,202 groups, 50 percent have a ratio bigger than 1.05, while less than 9 percent have a ratio less than 0.95. A closer examination of the ratio by age indicates that the gender bias (against either sex) is more prevalent between ages 1 to 15.

The linear relationship between national average RePLY ($r_k$) and the national life expectancy at birth ($e_{0,k}$) can also be observed for each gender as a group. That is,

$$r_k^g \approx \frac{e_{0,k}^g}{e_0^g}, \quad g = m, f; \quad \text{and hence,} \quad \frac{r_k^m}{r_k^f} = \frac{e_{0,k}^m}{e_0^m} / \frac{e_{0,k}^f}{e_0^f}.$$  

Thus, the ratio of RePLY for the two genders in a country is equal to the ratio of their life expectancies normalized by the ratio of the reference country. Essentially the reference country’s ratio is used as a benchmark for the “natural difference” in life expectancies between the two genders in order to assess whether the observed difference in a country exceeds that natural difference.

Figure 5 further examines the relationship of gender inequality at national level (i.e. $r_k^m / r_k^f$) against life expectancy at birth. From Figure 5, it can be seen that the vast majority of the countries with relatively low life expectancy at birth (and expectedly low income) witness higher inequality against females. On the other hand, for countries with relatively high life expectancy at birth, inequalities against males and females are equally prevalent. Countries that have the highest inequalities against females are most low income South Asian or African, such as Nepal (1.087), Botswana (1.085), Namibia (1.085), and Maldives (1.082). On the other hand, countries that have the highest inequalities against males are
most former Soviet Union members, including Russia (0.893), Kazakhstan (0.918), Belarus (0.907) and Latvia (0.919).

4.4 Individual-based Health Inequality

Table 3 shows the estimates of individual-based health inequality of a number of countries using various measures. The figures across different measures are not strictly comparable. Nevertheless, their indications of the relative degree of inequalities between countries are very similar. For instance, the inequality in South Africa is about 20 percentage higher than in India, more than twice of Russia and China, 5.5 times of the United States, and over 20 times of Japan. In general, countries with higher life expectancy at birth tend to have lower health inequality. This result is confirmed in Figure 6 which plots various health inequality measures against life expectancy at birth for the 191 countries. Despite the general negative relationship between health inequality and life expectancy at birth, a closer examination of individual series in the figure shows that the relationship is sensitive to the measure being used. As an illustration, Figure 7 shows a plot of the WHO Index of RePLY against life expectancy at birth. The overall negative relationship between the two is coupled with a large variation of health inequality values for a given life expectancy at birth, and the variation tends to increase as life expectancy declines. It is found that inequality measures with a larger value of parameter $\alpha$ tend to have greater variations. This is not surprising because a larger value of $\alpha$ implies that the inequality measures are more sensitive to ‘extreme’ observations. Overall, the result supports the argument that health inequality should be considered as a separate parameter from the average level of health in evaluating the health status of a population.

Figure 8 is a plot of the WHO Index and Gini coefficient of RePLY, respectively, against income inequality measured by Gini coefficient. Due to problems of non-availability
of income inequality data, only 77 countries are included in this graph. Out of these 77 countries, 29 are OECD countries. Income inequality data are drawn from the World Inequality Database of the World Institute for Development Economics Research (WIDER 2005). The database has numerous income inequality indices. We use those based on disposable income wherever possible, otherwise we use those based on net income. Only countries being classified as having reliable data by WIDER are selected. If income inequality indices are not available for the year 2000 for a country, indices for the year next closest is used, allowing a maximum time difference of 5 years.

It can be seen from Figure 8 that, while there is an overall positive relationship between the two health inequality measures and the income inequality measure, there are also large variations of health inequality estimates for any given income inequality estimate. The result indicates that in order to understand the determinants of health inequality, we need to consider other socioeconomic factors besides income. For instance, countries that have the highest inequalities measured by WHO Index of RePLY are most countries that experienced prolong military conflicts, such as Afghanistan (0.148), Niger (0.146), Sierra Leone (0.140) and Angola (0.129).

Lastly, we ask the question how important it is to distinguish avoidable and unavoidable deaths in measuring health inequalities. To answer this question, we compare between the Gini coefficients of RePLY and age-at-death. The Gini coefficient of age-at-death provides a conventional health inequality measure that does not distinguish avoidable and unavoidable deaths. We do not use the WHO index here because due to the parameter values of $\alpha = 3$ and $\beta = 0.5$, the index value depends the unit in which the health outcome is measured. Since RePLY has no unit while age-at-death is measured in years, comparing their WHO index values can be misleading. On the contrary, Gini coefficient is independent of measurement unit and therefore suitable for the comparison purpose here.
Figure 9 shows a scatter plot of Gini coefficient of RePLY against that of age-at-death. It can be observed that for all 191 countries, the Gini coefficient of age-at-death overestimates the state of health inequality as indicated by the Gini coefficient of RePLY. On average, the Gini coefficient of age-at-death is 43 percent larger than that of Reply. However, the extent of overestimation varies with the degree of inequality. The error is quite small when inequality is high, but it increases rapidly as inequality declines. For instance, for the OECD countries, the Gini coefficient of age-at-death typically overstates their health inequalities by more than 100 percent. Furthermore, while the Gini coefficient of RePLY can decline to nearly zero, the Gini coefficient of age-at-death seems to be bound below at around 0.1. These results can be explained by the fact, when inequality is very high, most deaths are avoidable, therefore not distinguishing avoidable deaths from unavoidable deaths will have little affect on the estimation of health inequality, and the two Gini coefficients give very similar estimates. On the other hand, when health inequality is low, a substantial proportion of deaths are unavoidable; failing to recognize this will overstate the inequality amongst the unavoidable deaths. In the extreme case that all deaths are unavoidable, the Gini coefficient of RePLY will be equal to zero, while that of age-at-death will be of a positive value, depending on the distribution of the deaths along the age line. In conclusion, the empirical results indicate that distinguishing avoidable and unavoidable deaths is of great importance in measuring health inequality.

5. Conclusion

In recent years, the World Health Organization has advocated that, besides improving the average level of health, a health system should also try to reduce inequalities that are caused by conditions amenable to intervention. To meet this challenge, it is necessary to first identify health outcomes that are amenable to intervention and those that are not. To this
end, this paper proposes a new health indicator that distinguishes between avoidable and unavoidable deaths. The new indicator measures the degree of realization of potential life years (RePLY) for individuals. Those who die of unavoidable causes are considered having fully realized their potential life years that nature permits, whereas those who die of avoidable causes are considered having realized a proportion of their potentials. Avoidable deaths, by definition, are amenable to intervention. A population will have lower health inequality measured by RePLY if either the prevalence of unavoidable deaths is higher or those who die of avoidable causes have realized a larger proportion of their potential length of life. Therefore, RePLY based inequality measures indicate only health inequalities that are amenable to intervention. Yet another advantage of using RePLY to measure health inequalities is that, as natural mortality differences due to age and gender have been controlled for, it allows us to measure health inequalities between age groups, between genders, and between all individuals within a population.

The new indicator is applied to measure health inequalities for 191 countries in year 2000 using mortality data collected by WHO. The new measure proposed here identified substantial health inequalities between age groups even for countries with high life expectancy at birth, such as Japan. It has also identified large variations in gender inequalities across age groups within individual countries, and large variations in gender inequalities across countries. At the individual level, it was found that while overall countries with higher life expectancy at birth tend to have lower health inequalities, there are substantial variations in health inequality statuses for any given life expectancy. The result therefore gives support to WHO’s plea to use health inequality as a distinct parameter from the average level of health in assessing the performance of health systems.

The present paper is part of a research program on measuring avoidable and unavoidable health risks. A limitation of the present paper is its omission of non-fatal health
outcomes. However, the concept of avoidable and unavoidable health risks can be readily extended to include both fatal and non-fatal health outcomes, providing that there are sufficient data to construct a comprehensive health risk profile for the reference country. This is an obvious direction of our future research in health inequality.

Reference

Woolsey, TD 1981, Toward an index of preventable mortality, 85, Department of Health and Human Services, Hyattsville.
Appendix

The discussions of the construction of the mortality risk profile and life expectancy for the reference country, as well as that of RePLY for individual countries assume age \( x \) and its associate probability of dying are continuous variables. However, the life tables compiled by WHO are period abridged life tables, which divide the continuous age line into 22 discrete sections. The first group covers ages between 0 and 1, the second between 1 and 5, the third between 5 and 10, and so forth. The last age group covers 100 and above. As a result, the construction of the mortality risk profile for the reference country and the calculation of RePLY need to be adjusted to accommodate the use of discrete age brackets.

A.1 Mortality Risks and Life Expectancy in the Reference Country

Let \( s \) be an index of age bracket, \( s = 1, 2, \ldots, 22 \). The conditional probability that a person of gender \( g \) in country \( k \) who survives to age \( x_s \) will die before reaching the age \( x_{s+1} \) is denoted by \( q_{ik}^g \). Let \( \bar{q}_s^g \) be the conditional probability of dying for a person in the reference country who survives to age \( x_s \).

Then, \( \bar{q}_s^g \) is defined as

\[
\bar{q}_s^g = \begin{cases} 
\min\{q_{ik}^g, k = 1, 2, \ldots, 191\}; & i = 1, 2, \ldots, 21 \\
1; & i = 2 
\end{cases}
\quad \text{(14)}
\]

Let \( \bar{e}_i^g \) be the life expectancy of a person of gender \( g \) that survives to age \( x_s \) in the reference country:

\[
\bar{e}_i^g = \begin{cases} 
\bar{q}_s^g y_s + (1 - \bar{q}_s^g)(\bar{e}_{s+1}^g + y_{s+1}) - x_s^g; & \text{if } i \leq 21 \\
1/\bar{M}_22^g; & \text{if } i = 22 
\end{cases}
\quad \text{(15)}
\]

where \( y_s \) is the average value of the interval \( x_s \) and \( x_{s+1} \); \( \bar{M}_22^g = \min\{M_{22,k}^g, k = 1, 2, \ldots, 191\} \), and \( M_{22,k}^g \) is the actual mortality rate of the last age group. The average value, \( y_s \), of the
interval $x_i$ and $x_{i+1}$ depends on the distribution of mortality risks within the interval. It is not necessarily a simple mid-point value of $x_i$ and $x_{i+1}$.

### A.2 RePLY

For an avoidable death that occurs at age $y$ in group $s$ (i.e. $y$ is between $x_i$ and $x_{i+1}$).

Should the person have access to the same amount of resources as his/her peers do in the reference country, he/she would not have died of avoidable causes in that period and therefore would have reached the next age bracket. In other words, at the absence of avoidable mortality risks, a person who has already survived $x_i$ is expected to live till $\tilde{e}_s^{x_i} + x_{i+1}$. Hence, for $s < 22$, the realization of potential life years (RePLY) is defined as

$$ R_s^y = \begin{cases} 
1 & \text{for unavoidable deaths} \\
\frac{y}{\tilde{e}_s^{x_i} + x_{i+1}} & \text{for avoidable deaths}
\end{cases} \quad (16) $$

For the last age group (i.e. $s = 22$), there is only a lower bound of age 100 but no upper bound, and we can not separate avoidable and unavoidable deaths. Thereby the RePLY is calculated slightly differently as

$$ R_{22}^y = \frac{\tilde{e}_s^{22} + 100}{\tilde{e}_s^{22} + 100} \quad \text{for all deaths} \quad (17) $$

The calculation of the IMD and IID can be further elaborated as follows:
\[ \text{IMD}(\alpha, \beta) = \frac{\sum |R_{i,k} - r_k|^\alpha}{d_k(r_k)^\beta} \]
\[ = \frac{\sum \sum \left\{ \frac{u^g_{ik} \left[ 1 - r_k \right]^\alpha + a^g_{ik} \left[ y_s / (\bar{e}^g_{s+1} + x_{s+1}) - r_k \right]^\alpha \right\}}{d_k(r_k)^\beta} \]
\[ = u^g_{ik} \left[ 1 - r_k \right]^\alpha + \sum \sum \left\{ a^g_{ik} \left[ y_s / (\bar{e}^g_{s+1} + x_{s+1}) - r_k \right]^\alpha \right\} \]
\[ (18) \]
\[ \text{IID}(\alpha, \beta) = \frac{\sum |R_g - R_i|^\alpha}{2(d_i)^2(r_k)^\beta} \]
\[ = \frac{\sum \sum \left\{ u^g_{ik} a^h_i \left[ 1 - y_s / (\bar{e}^g_{s+1} + x_{s+1}) \right]^\alpha + a^g_{ik} a^h_i \left[ y_s / (\bar{e}^g_{s+1} + x_{s+1}) - y_s / (\bar{e}^h_{s+1} + x_{s+1}) \right]^\alpha \right\}}{2(d_i)^2(r_k)^\beta} \]
\[ (19) \]

where \( g \) and \( h \) are gender indexes, \( p \) and \( s \) are age group indexes.

### A.3 Relationship between average RePLY and ratio of life expectancies

There is a close relationship between average RePLY of a country and the ratio of life expectancies at birth between the country and the reference country. Consider a country of population size equal to \( N \), within which individual \( i \) lives for \( x_i \) years and his/her potential total life span is equal to \( E_i \). The average RePLY of the country is thus equal to the average of all individual’s ratio of years of life lived and the expected potential years to be lived:

\[ r = \frac{1}{N} \sum_{i=1}^{N} \frac{x_i}{E_i} \]
\[ (20) \]

On the other hand, the ratio of life expectancies at birth is the ratio of the average years of life lived by all individuals in the population and the average of their expected potential years to be lived:
\[
\frac{\bar{x}}{\bar{E}} = \frac{\sum_{i=1}^{N} x_i}{\sum_{i=1}^{N} E_i}
\]

(21)

Thus, the former is the average of the ratios and the other is the ratio of the averages. While they are in general not equal to each other, one may provide a good approximation for the other. This is because the ratio of averages is actually just a weighted average of the ratios:

\[
\frac{\bar{x}}{\bar{E}} = \frac{\sum_{i=1}^{N} x_i}{\sum_{i=1}^{N} E_i} = \sum_{i=1}^{N} \left( \frac{E_i}{\bar{E}} \right) \left( \frac{x_i}{E_i} \right)
\]

(22)

where the weight is the expected length of life for each individual divided by the population average. As a result, as the variation of \(E_i\) reduces, \(\bar{x} / \bar{E}\) becomes a better approximation of the average Reply \(r\).
Table 1 Mortality Profile of the Reference Country: Male Population

<table>
<thead>
<tr>
<th>Age</th>
<th>Country</th>
<th>Conditional probability of dying</th>
<th>Life expectancy</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Singapore</td>
<td>0.00373</td>
<td>79.36</td>
</tr>
<tr>
<td>1</td>
<td>Sweden</td>
<td>0.00052</td>
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<td>5</td>
<td>Malta</td>
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<td>Iceland</td>
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<td>Malta</td>
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<td>0.00300</td>
<td>55.00</td>
</tr>
<tr>
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<tr>
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<td>40.48</td>
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<tr>
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<td>35.73</td>
</tr>
<tr>
<td>50</td>
<td>Iceland</td>
<td>0.01735</td>
<td>31.04</td>
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<td>55</td>
<td>Sweden</td>
<td>0.03091</td>
<td>26.54</td>
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<td>Sweden</td>
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<td>22.31</td>
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<tr>
<td>65</td>
<td>Switzerland</td>
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<td>0.12906</td>
<td>14.91</td>
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<td>Monaco</td>
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<td>1</td>
<td>2.69</td>
</tr>
</tbody>
</table>

Note:
1. The column shows the lower bound of the age group.
2. The column shows the probability of a person dying before reaching the next age bracket.
3. The column shows the country that determines the envelopment for a given age group.
4. The column shows life expectancy at different age groups, thus, life expectancy at age zero is the life expectancy at birth.
### Table 2 Mortality Profile of the Reference Country: Female Population

<table>
<thead>
<tr>
<th>Age</th>
<th>Country</th>
<th>Conditional probability of dying</th>
<th>Life expectancy</th>
</tr>
</thead>
<tbody>
<tr>
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<td>Denmark</td>
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<td>Israel</td>
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<td>Andorra</td>
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<td>Japan</td>
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<td>14.55</td>
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<td>80</td>
<td>Japan</td>
<td>0.20225</td>
<td>10.92</td>
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<td>Monaco</td>
<td>0.31431</td>
<td>8.06</td>
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<td>90</td>
<td>Antigua and Barbuda</td>
<td>0.48322</td>
<td>5.61</td>
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<tr>
<td>95</td>
<td>Grenada</td>
<td>0.66230</td>
<td>3.98</td>
</tr>
<tr>
<td>100</td>
<td>Grenada</td>
<td>1</td>
<td>2.86</td>
</tr>
</tbody>
</table>

Notes as for Table 1.
Table 3 Individual-based Health Inequality Estimates within Countries

<table>
<thead>
<tr>
<th>Country</th>
<th>Life expectancy at birth</th>
<th>absolute mean deviation</th>
<th>variance</th>
<th>Gini coefficient</th>
<th>WHO index</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>IMD (α=1, β=1)</td>
<td>IMD (2, 1)</td>
<td>IID (1, 1)</td>
<td>IID (3, 0.5)</td>
<td></td>
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<tr>
<td>USA</td>
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<td>0.1005</td>
<td>0.0217</td>
<td>0.0584</td>
<td>0.0116</td>
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<td>Japan</td>
<td>81.18</td>
<td>0.0284</td>
<td>0.0053</td>
<td>0.0148</td>
<td>0.0030</td>
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<tr>
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<td>70.87</td>
<td>0.1677</td>
<td>0.0573</td>
<td>0.1107</td>
<td>0.0395</td>
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<tr>
<td>India</td>
<td>61.19</td>
<td>0.3076</td>
<td>0.1228</td>
<td>0.2050</td>
<td>0.0803</td>
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<tr>
<td>Russian Fed.</td>
<td>66.09</td>
<td>0.2066</td>
<td>0.0586</td>
<td>0.1404</td>
<td>0.0296</td>
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<tr>
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<td>0.4241</td>
<td>0.1503</td>
<td>0.2785</td>
<td>0.0775</td>
</tr>
</tbody>
</table>
Figure 1 Conditional Probability of Death at Age $x$

Conditional probability of dying, $q_x$.
Figure 2 Males Average RePLY by Age-at-Death

Figure 3 Female Average RePLY by Age-at-Death
Figure 4 Ratio of Male to Female Average RePLY by Age-at-Death

Figure 5 Ratio of Male to Female Average RePLY against Life Expectancy at Birth across Countries
Figure 6 RePLY Inequality Measures against Life Expectancy at Birth across Countries

Figure 7 WHO Index of RePLY against Life Expectancy at Birth across Countries
Figure 8 Health Inequality against Income Inequality across Countries
Figure 9 Gini Coefficients of RePLY and Age-at-Death across Countries