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Avoidable Mortality Risks and Measurement of Wellbeing and Inequality

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Abstract

This paper proposes a data envelopment method to separate avoidable and unavoidable mortality risks. As unavoidable mortality is the result of nature, only avoidable mortality is of relevance in measuring wellbeing and inequality. The new method is applied to a dataset consisting of life tables for 191 countries in the year 2000 to obtain a reference distribution of unavoidable mortality risks. The reference distribution is used to improve on the standard age-at-death measure to obtain an age-at-avoidable-death measure. Comparing with the original measure, age-at-avoidable-death provides a very different picture of wellbeing, and more so when it comes to inequality measures.

Keyword: Mortality risk, life table, avoidable deaths, age-at-death, inequality.
JEL Classification: D6, I12

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1. Introduction

Mortality rate and its derivatives have long been used both specifically as a health indicator (e.g. age-at-death and years of potential life lost) and generally as a social indicator (e.g. life expectancy and infant mortality rates). Often these measures are used in policymaking and evaluation. 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. With the prominence of mortality statistics in policy setting, improvement in their measurement could have significant impacts. In this paper, we develop a method to improve on current mortality measures so that the resulting measures can serve as more meaningful socioeconomic indicators and are, thus, more instrumental in policymaking.

Amartya Sen (1995) argues that mortality rates provide a better measure of wellbeing and inequality than income. He reasons that wealth is useless without the capability to enjoy it, and death strikes at the heart of this capability in that death directly diminishes our ability to function and removes our freedom to pursue life-enriching activities. Translated into more practical terms, mortality can be considered as a composite measure of a number of basic but essential physiological needs: nutrition, basic education, health, sanitation, water, shelter, and safety. While the provision of these needs is clearly related to income or wealth, mortality-based wellbeing measures have "the advantage of capturing the impact on individuals, not only of non-market factors but also of income net of taxes, transfer payments and social services, without raising all the difficulties of income per head measures, such as the appropriate unit (individual, household or family), the appropriate magnitude (capital, consumption income), the appropriate set of prices (market prices, international prices), what to value as final goods and what as costs, etc." (Hicks & Steeten 1979).

Despite the aforementioned merits of mortality as a wellbeing indicator and the fact that it has already been widely used as a yardstick to evaluate policy outcomes, a fundamental issue has not yet been addressed satisfactorily: how to separate avoidable mortality from unavoidable, or natural, mortality? Some obvious examples of avoidable deaths include deaths due to violence or starvation. In comparison, what constitutes unavoidable deaths is less obvious. On the one hand, even for diseases without effective cure, it is still possible to take measures to avoid infection at the first place and, thus, deaths due to such non-curable diseases are not entirely unavoidable. On the other hand, even for illnesses against which effective treatments have been developed, there are chances that some patients can not survive them due to their own peculiar health conditions. To what extent can such deaths be classified as unavoidable or avoidable is not a straightforward issue. Notwithstanding the difficulties in classifying the nature of death, the fact that human beings are mortal is the strongest evidence that some mortality risks are unavoidable.

The basic premise of the paper is: *given that death which is unavoidable is beyond the control of humanity, it has no welfare implications and, thus, should be excluded from any measure of wellbeing*. The distinction between avoidable and unavoidable mortality has vital policy implications. If unavoidable mortality can be measured and, therefore, separated from observed mortality of various population groups (e.g. by gender, income, race), the resulting measure of avoidable mortality will provide a much more meaningful indication of their socioeconomic conditions. This will assist policymakers to allocate resources to areas where they can *possibly* *make a difference* and, therefore, avoid wastage of resources as a result of targeting the wrong goals derived from distorted measures of wellbeing.

Avoidable mortality risk is not an entirely new concept. For instance, besides the previous examples of violence and starvation, death caused by consumption of tobacco, poor diet and physical inactivity (i.e. obesity), alcohol consumption, toxicants, illicit use of drug, and vehicle accidents are classified as preventable by the Centers for Disease Control and Prevention of the United States (CDC 1986). A limitation of this classification method is that it can identify only the most obvious avoidable deaths and cannot be easily generalized to handle disease related deaths. In countries with limited healthcare capacity, classification of deaths may be inaccurate. Furthermore, as death is rarely monocausal, selection of a single underlying cause may not be practical. In summary, although the concept of preventable death has been applied in evaluating public health, due to the shortcomings of classification methods the resulting measures are not comprehensive enough to be a social indicator.

This paper addresses this issue by developing a method to separate avoidable and unavoidable mortality risks using the information embodied in life tables compiled by the World Health Organization (WHO) for 191 countries in the year 2000. This method identifies a death as either avoidable or unavoidable based on the *probability* that each scenario arises, rather than the actual cause of death and, therefore, can circumvent the aforementioned problems of classification methods. The concept of avoidable mortality risk is versatile and in principle can be applied to any mortality-based measure of wellbeing. As an illustration, we apply it to improve the length-of-life or age-at-death measure in order to examine both average wellbeing and general inequality. Le Grand (1987; 1989) first used the dispersion of age-at-death as an inequality measure, but without distinguishing avoidable and unavoidable deaths.

It should be pointed out at the outset that even after controlling for unavoidable mortality risks, mortality still has other limitations as a wellbeing measure in that it does not inform us about the aspects of life that have little fatal consequences. For instance, it has long been argued that morbidity and disability are as important as mortality in defining quality of life (Gakidou, Murray & Frenk 2000). Therefore, ideally we would like to measure not only the years of life being lost due to avoidable risks, but also the years of "quality life" being lost as a result of avoidable but non-fatal health outcomes. The main difficulty here is that each non-fatal health outcome is unique and, therefore, establishing a standardized unit of measure can be plagued with controversy (Murray 1996: p.22). As a result, we confine our study to mortality.

2. Reference Distribution of Unavoidable Mortality Risks

2.1 Concept

Socioeconomic factors play a key role in determining mortality risks. A study by Moriguchi et al. (2004) shows that Japanese immigrants from Okinawa living in Brazil face a higher mortality risk from cardiovascular diseases and have a shorter mean life expectancy compared with their counterparts living in Okinawa. The higher mortality risks of Okinawa immigrants in Brazil were due to their change of diet to a lower intake of fish and higher intake of meat. The study concludes that the effect of lifestyle on longevity can be large enough to modulate the expression of genes.

Since mortality risks are not static, they can be reduced by improving technology and resource availability, especially those related to nutrition, safety, and health. Therefore, a country with better socioeconomic conditions pertaining to a particular population group will see a lower mortality rate for that group. However, even under the most favourable socioeconomic conditions that are feasible at a point in time, some mortality risks cannot be completely eradicated, such as those related to genetic factors and natural events. 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 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". The mortality profile of this hypothetical reference country is constructed using the data envelopment method described below.

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.

The construction of the reference country mortality profile makes use of the information encoded in the life tables. The use of life tables is more appropriate than raw mortality data as it takes into account long-term effects of mortality risk differentials. The life table provides information on the conditional probability of death, q_i for each age group i. Therefore, if q_i is plotted against age, x_i, then $q_{N+1} = 1$, i.e., a person must die at age x_{N+1}, for a sufficiently large value of $N+1$.

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_n are better off in Country 1, while those above x_n 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 j who survives to age x_i will die before reaching the age x_{i+1} is denoted by q_{ij}. Let $\tilde{q}_i$ be the conditional probability of dying for a person in the reference country who survives to age x_i.

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

$$\tilde{q}_i = \min\{q_{ij}, j = 1, 2, ..., K\};\ i = 1, 2, ..., N \qquad (1)$$

$$\tilde{q}_{N+1} = 1 \qquad (2)$$

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 equations (1) and (2). In life tables, life expectancy in country j, e_{ij}, is defined as the number of years a person is expected to live if one has survived to age x_i. Let $\tilde{e}_i$ be the life expectancy of a person that survives to age x_i in the reference country:

$$\tilde{e}_i = \begin{cases} \tilde{q}_i u_i + (1-\tilde{q}_i)(\tilde{e}_{i+1} + u_{i+1}) - x_i & \text{if } i \le N \\ 1/M^*_{N+1} & \text{if } i = N+1 \end{cases} \tag{3}$$

where u_i is the average value of the interval x_i and x_{i+1}; M^*_{N+1} = min { $M_{N+1,j}$, j = 1, 2…K }, and M_{N+1} is the actual mortality rate of age group $N+1$ (in the present study, $N+1$ = 22). The average value, u_i, 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}.

2.3 Mortality Risks for the Reference Population

The proposed method is applied to life tables of 191 countries in the year 2000 compiled by the World Health Organization (WHO 2002). The mortality risk profile for the male and female populations in the reference country are shown in Table 1 and Table 2. 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. We observe that countries contributing to the profile of reference populations are quite different for male and female populations and emphasise the need to construct gender-based reference mortality risk profiles. High income countries such as Sweden, Switzerland and Japan only make up about half of the list of countries defining the reference mortality distribution. Mediterranean countries like San Marino and Malta, and Caribbean countries such as Antigua and Barbuda, and Grenada fill the other half. Two countries that do not fit in this income-geography pattern are Estonia (from Eastern Europe) and Slovenia (from Central Europe). In the year 2000, these two countries have GDP per capita (PPP) in constant 2000 international dollars equal to only 9,779 and 16,896, respectively, compared with 33,989 in the United States.

The mixture of high-income and low and middle-income countries contributing to the reference country lists substantiates the claim that income per capita can only capture certain aspects of wellbeing. For instance, despite its high income per capita the United States is not identified as a reference country in any age group. The fact that countries like Sweden, Switzerland and Brunei contribute to the reference country suggests that for the same average income level, an egalitarian society may have longer life expectancy. 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.

The domination of Mediterranean and Caribbean countries in Tables 1 and 2 should not be surprising, these countries are known to have high life expectancy due to their healthy lifestyle. A study has shown that there is a link between longevity and the Mediterranean diet (Trichopoulou et al. 2005). The less stressful Mediterranean and Caribbean lifestyles are also likely to add to longevity of the people in these regions. Moreover, the contributing countries are dominated by small countries. The only large country in terms of population is Japan. This is probably because as larger countries are less homogeneous, it is much harder to provide equally favourable socioeconomic conditions to their citizens in different regions. As a result, mortality rates vary more across different regions in large countries than in small countries, which may result in higher average mortality rate of the former.

The mortality profile of the reference country is a proxy for unavoidable mortality risks for the year 2000. The mortality risk faced by every age group in the reference country is not higher than any from the same age group in the remaining 191 countries. This implies that people in the 191 countries face a certain degree of avoidable mortality risks, which is in addition to unavoidable mortality risks common to all citizens in the world. Therefore, life expectancy at any age for the reference country is higher than that observed in all the 191 countries used in the dataset. As an illustration, Japanese males and females have the highest life expectancy at birth amongst all the 191 countries, of 77.55 years and 84.66 years, respectively. In comparison, the life expectancy at birth for males and females in the reference country, as shown in the top right hand corner of Tables 1 and 2, are 79.36 years and 85.55 years, respectively.

2.4 Robustness of the Reference Distribution

The data envelopment method, which is mostly used in productivity and efficiency analysis, has been criticized for being sensitive to the presence of outliers in the data. Nonetheless, our method is largely immune from this problem because mortality rate figures in life tables are produced from smoothing out the actual, raw mortality figures. As a result, extreme observations would not enter the construction of the reference distribution of unavoidable mortality risks. Notwithstanding this safeguard, we further examine this robustness issue empirically. We construct the reference distribution using alternative data points and then compare the resulting life expectancy at birth of the reference country with the original one. Differences in life expectancy at birth are used for comparison because it measures the accumulation of differences in mortality rates of all age groups. If any of the observations used in the construction of the mortality rate distribution of the reference country are outliers, using alternative data points should change the life expectancy at birth of the reference country substantially. We conduct several tests of robustness of the results.

Firstly, we use the *second* lowest conditional probability of dying for each age group to construct the reference distribution. The result is that the reference country life expectancies at birth for males and females reduce merely by 0.59 years and 0.56 years, or 0.74 percent and 0.65 percent, respectively.

Secondly, we drop all the countries defining the reference distribution at the first stage and construct the unavoidable mortality distribution using the remaining countries. For example, Japan is one of the countries defining the original female reference distribution, in the second stage Japan is excluded when the female reference distribution is reconstructed. This procedure essentially peels off all the countries defining the original reference distribution in the first stage of our analysis. To see the difference between this and the previous method, consider Singapore as an example. Singapore has the lowest mortality risk for the first age group of male but not in other age groups. Under the first method it is still possible for Singapore to be one of the second tier countries for the male distribution (but of different age groups), but under the second method Singapore will be excluded from the entire male group (but remains in the female group). Therefore, the change under the second method will be at least as large as that in the first method. Indeed, the reference country life expectancy at birth for males and females reduce by 1.05 years and 1.88 years, or 1.32 percent and 2.20 percent, respectively. Although the changes are bigger as expected, their magnitudes remain very small.

Amongst the 191 countries in the sample, 65 have reasonably complete vital statistics. Another test of robustness is therefore to use only these 65 countries to construct the reference distribution to examine if there are any errors due to using constructed data in life tables. The result is that the reference country life expectancy at birth for males reduces negligibly by 0.12 years or 0.15 percent, and that of females is not affected. This is because amongst all the original list of contributing countries, only one country, Brunei, in the male group has incomplete vital statistics and, thus, is excluded under this method.

Overall, we can conclude that the reference distribution of unavoidable mortality risks constructed using the data envelopment method is robust when working with life table data and, more importantly, when the dataset covers a large number of countries.

While the constructed reference distribution of unavoidable mortality risks is robust to measurement errors in the mortality data, it could still be sensitive to the population grouping of the underlying life tables. For instance, even if Japan has the highest life expectancy amongst all the 191 countries, there are still differences within the country. Okinawa prefecture, which is renowned for longevity, has 39.5 centenarians per 10,000 people, compared to 14.1 for Japan as a whole. Consequently, if we use life tables for different population groups within a country, such as by province or state, or by race, the resulting reference distributions of unavoidable mortality risks might be different. However, the availability of standardized life tables confines us to the use of national level life tables.

3. Avoidable Mortality Risk as a Measure of Wellbeing

The reference country mortality profile constructed here is used as a benchmark to measure natural 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 is either less resourceful or less effective 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*. In the remainder of this paper we demonstrate how the constructed reference distribution of unavoidable mortality risks and the resulting measure of avoidable mortality risk can be used in deriving measures of wellbeing and inequality. In this paper we use age-at-death of all avoidable deaths as the basis for welfare measurement. In a series of other studies in progress and papers under preparation, we explore a number of other measures of wellbeing defined on the basis of avoidable mortality risk concept developed in this paper.

3.1 Average Age-at-Avoidable-Death

Age-at-death is used mostly to identify the impacts of specific fatal causes, such as influenza (Tillett, Smith & Gooch 1983) and sickle cell disease (Platt et al. 1994). Notwithstanding, age-at-death can also be used as a social indicator. Specifically, we can measure the overall wellbeing of country j with national average age-at-death:

$$Average\ Age\text{-}at\text{-}death_j = \frac{\sum_i \sum_s D_{ij}^s u_i^s}{\sum_i \sum_s D_{ij}^s} \tag{4}$$

where D_{ij}^s is the number of deaths for age group *i* of gender *s* in the actual population in country *j*, *s* = male, female; u_i^s = average (expected) age-at-death of a deceased person in the group. A greater national average age-at-death implies a higher average length of life for those who died in a given year and, therefore, is unambiguously reflecting greater welfare, *ceteris paribus*.

Age-at-death is a potentially useful social indicator because it can provide a uniform framework to measure both overall and distributional aspects of wellbeing within a community. One can in principle measure the age-at-death of every person deceased in a given year in a population and therefore the corresponding welfare distribution at individual level. This is in contrast to life expectancy or infant mortality rates, which also serve as an overall measure of wellbeing but are of limited applicability as a distributional measure. This is because the two parameters can only be defined for the whole population or for a social class, but not for individuals. Income or wealth in general, is another parameter that can be used for both overall and distributional wellbeing measures. However, income is not considered to be as comprehensive a measure as mortality rate, and is burdened with difficulties in capturing non-market factors, measurement issues, price conversion and data collection. On the contrary, age-at-death is largely free of these problems.

Though age-at-death has several of these merits, two adjustments have to be made for it to be a useful social indicator.

Firstly, since age-at-death covers only a small portion of the population – those who died in the year of survey, it may not reflect the wellbeing of the whole population, especially those who have survived that particular year. This issue can be addressed by using a stationary population associated with a given distribution of mortality risks. The stationary population of a country is constructed by repeatedly subjecting the population to the same age-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 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.

Secondly, since unavoidable deaths have no welfare implications, they should be excluded from the measurement. This can be achieved by making use of the distribution of unavoidable mortality risks. The number of deaths for an age group *i* in a stationary population *j*, $d_{ij} = n_{ij}q_{ij}$, is observable, where n_{ij} is the stationary population size of age group *i* and q_{ij} is its conditional probability of dying. Suppose the number of unavoidable deaths for the group *i* is equal to d^*_{ij}. This number is not directly observable but can be imputed from $d^*_{ij} = n_{ij}\tilde{q}_i$, where $\tilde{q}_i$ is the conditional probability of dying for the same age group in the reference country, which is, by assumption, free of avoidable mortality risks.

Hence, we can express the number of avoidable deaths for the group, a_{ij}, as

$$\begin{aligned} a_{ij} &= \textit{observed deaths} - \textit{unavoidable deaths} \\ &= d_{ij} - d^*_{ij} \\ &= n_{ij}q_{ij} - n_{ij}\tilde{q}_i \\ &= n_{ij}q_{ij}(1 - \tilde{q}_i / q_{ij}) \\ &= d_{ij}(1 - \tilde{q}_i / q_{ij}) \end{aligned} \tag{5}$$

where $\tilde{q}_i / q_{ij}$ is the probability that an observed death is unavoidable. Therefore, the closer is q_{ij} to $\tilde{q}_i$, the larger is the number of unavoidable deaths for a given total number of deaths and, thus, the smaller is the number of avoidable deaths.

By applying the above process to the two genders separately, we obtain the following data for the purpose of constructing wellbeing measures: a_{ij}^s = observed number of avoidable deaths in age group *i* of gender *s* in country *j*; u_i^s = average age-at-death of a deceased person in a given group. There are in total 22 age groups, with *i* = 1 for ages between 0 and 1, *i* = 2 for ages between 1 and 5, *i* = 3 for ages between 5 and 10, and so forth.

Two measures of wellbeing, one used in comparing levels across countries and another used in examining the distribution of wellbeing, are explored further in the next two sections, respectively. In any overall assessment of wellbeing across countries it is necessary to consider both level and inequality measures.

3.2 Average AAD as an Wellbeing Measure

We define the average AAD for the stationary population of country *j* as:

$$Average\ AAD_j = \frac{\sum_i \sum_s a_{ij}^s u_i^s}{\sum_i \sum_s a_{ij}^s} \tag{6}$$

A greater average AAD means that those who died of avoidable causes have a higher average length of life and, therefore, is unambiguously welfare enhancing, *ceteris paribus*.

Using the life tables compiled by the WHO, we can compute the values of average AAD for the 191 countries in 2000 and rank them accordingly. Table 3 provides the average AAD for the top and bottom ten ranked countries according to average AAD. For instance, Cyprus ranks the sixth with an average AAD equal to 77.3 years, a few places ahead of the tenth, Japan, which has an average AAD equal to 77.1 years. However, the average AAD does not provide a full picture.

3.3 Share of Avoidable Deaths in Total Deaths as a Measure of Wellbeing

Using the information in the life tables, we can also compute another wellbeing measure – the proportion of avoidable deaths as a percentage of the total number of deaths. By definition a country with a smaller percentage of avoidable deaths has better socio-economic conditions that limit avoidable deaths. Figure 2 provides a plot of the average AAD against the share of avoidable deaths for the 191 countries. While there is a general negative relationship between the two measures especially when the average AAD is small, the relationship is not linear when the average AAD is over 50. In Table 3, the percentage shares of avoidable deaths for the top and bottom ten ranked countries are also listed along side with their average AAD. It is clear that the percentage share of avoidable deaths shows considerable variation among top ranking countries. In the previous example, it turns out that Japan has a proportion of avoidable deaths equal to 9 percent – the lowest amongst the countries, compared with the 38 percent for Cyprus. Since the two countries have very similar average AAD figures yet Japan has a much lower proportion of avoidable deaths, therefore we should rank Japan above Cyprus in terms of welfare comparison. This example demonstrates the need to consider both the average AAD and the proportion of avoidable deaths in measuring the average wellbeing of a population.

Hence, we propose a simple adjustment to the conventional average age-at-avoidable-death measure, incorporating the proportion of avoidable deaths into the average AAD measure:

$$Adjusted\ Average\ AAD_j = Average\ AAD_j\,(1-\alpha_j) \tag{7}$$

where

$$\alpha_j = \frac{avoidable\ deaths}{total\ number\ of\ deaths}.$$

The measure proposed here can be seen as a measure that treats both components, the average AAD and the percentage share of avoidable deaths, equally. If there is an *a priori* reason to accord differential weights to these measures, such weights could be incorporated in equation (7) leading to:

$$Adjusted\ Average\ AAD_j = \left(Average\ AAD_j\right)^{\omega}(1-\alpha_j)^{(1-\omega)} \tag{8}$$

where ω is a real number in the interval 0 to 1.

Robustness tests indicate that adjusted average AAD is not very sensitive to the value of weights used. The Pearson correlation coefficients of adjusted average AAD calculated using equation (7) and equation (8) with ω equal to 0.7 and 0.3 respectively, are greater than 0.97. Their Spearman rank correlation coefficients are also above 0.98, indicating that they rank countries very similarly. Therefore, in the remainder of this paper, we only report results of adjusted average AAD calculated using the equal weighting formula (7).

Figure 3 is a plot of the rankings of selected countries based on the *adjusted average AAD*. It can be seen that once adjusted for the proportion of avoidable deaths, Japan now emerges as the top country, well ahead of Cyprus which now ranks 27th.

To contrast the AAD measure with the age-at-death measures, we plot the adjusted average AAD against the average age-at-death in Figure 4. For the comparison purpose, the average age-at-death is also computed using stationary instead of actual population. Notwithstanding, since average age-at-death does not have a similar component to the proportion of avoidable deaths, the magnitude of the two measures in Figure 4 are quite different. Adjusted average AAD is of much smaller values than its counterpart, and spreads over a large range. However, overall the two measures are closely and positively related.

To see how useful adjusted average AAD is as a socioeconomic indicator we examine how it tracks some commonly used development indicators, viz., life expectancy, GDP per capita (PPP), and Human Development Index (HDI). The results are summarized in Table 4. Adjusted average AAD and life expectancy at birth have a Pearson correlation equal to 0.92 and a Spearman rank correlation equal to a very high 0.99. The high correlations with life expectancy should not come as a surprise as it is also computed based on mortality risks. Since unavoidable mortality risks are the same for every country, higher mortality risks must be due to higher avoidable mortality risks. As a result, adjusted average AAD and life expectancy are highly positively related. The Spearman rank correlation with GDP per capita is comparatively lower at 0.85. The Pearson correlation with GDP per capita is equal to merely 0.79, but it increases to 0.86 when the natural logarithm of GDP per capita is used, indicating a non-linear relationship between the two. Lastly, adjusted average AAD is also highly correlated with HDI, with the Spearman rank correlation and Pearson correlation equal to 0.91 and 0.90, respectively. Since HDI consists of life expectancy, GDP per capita (PPP), adult literacy rates and school enrolment ratio, its high correlation with adjusted average AAD can be considered as a validation of the capability of adjusted average AAD in describing the state of development.

So far we have focused on measures that can be used in comparing the levels of avoidable mortality risks across countries. However these measures do not adequately account for the distributional aspects underlying mortality risks. Different socioeconomic groups experience different levels of avoidable mortality risks which are reflected in the distribution of age-at-death or AAD across the population. These measures are discussed below.

3.4 AAD as a Basis for Inequality Measurement

Le Grand (1987; 1989) is probably the first to use the dispersion of age-at-death as an inequality measure. He measures the distribution of age-at-death of a population without distinguishing avoidable and unavoidable deaths. If the stationary total population (females plus males) is used for comparison reason, Le Grand's age-at-death Gini coefficient (hereafter abbreviated as Gini) is calculated as:

$$\textit{Age-at-death Gini}_j = \frac{\sum_h \sum_i \sum_r \sum_s d_{hj}^r \, d_{ij}^s \, | u_{hj}^r - u_{ij}^s |}{2 d_j \, u_j} \tag{9}$$

where h and i are age indices, r and s gender indices, d_{ij}^s the number of deaths for age group i of gender s in the stationary population in country j, $d_j = \sum_i \sum_s d_{ij}^s$ the total number of deaths, and $u_j = (1/d_j) \sum_i \sum_s d_{ij}^s \, u_{ij}^s$ the average age-at-death. Therefore, the age-at-death Gini takes into account of differences in length of life of all age-gender groups.

The corresponding Gini coefficient based on AAD for the total stationary population is calculated as:

$$\textit{AAD Gini}_j = \frac{\sum_h \sum_i \sum_r \sum_s a_{hj}^r \, a_{ij}^s \, | u_{hj}^r - u_{ij}^s |}{2 a_j \, v_j} \tag{10}$$

where $a_j = \sum_i \sum_s a_{ij}^s$ is the total number of avoidable deaths in country j, v_j the average AAD as defined in equation (6).

For both Gini coefficients, a fall in the absolute difference in the length of life $| u_{hj}^r - u_{ij}^s |$ means greater equality between groups in terms of longevity, which is welfare enhancing for a given average age-at-death or average AAD. At the same time, a rise in the average length of life, u_j or v_j, means greater longevity for the population as a whole, which is also welfare enhancing for a given distribution of age-at-death or AAD. Therefore, both Gini coefficients have the same welfare ranking order as income Gini coefficient for the same social utility function. Furthermore, unlike the average measure, the proportion of avoidable death does not feature in AAD Gini. This is because we are basically interested in measuring inequality in the ages of those who died in a given year due to avoidable mortality risks. In any overall welfare assessment it is necessary that both the adjusted average AAD and the AAD Gini are taken into account.

Figure 5 shows the rankings of selected countries based on their AAD Gini's. It is interesting to notice that although Japan has the highest adjusted average AAD, its AAD Gini is not the lowest. The top position is taken by Sweden. In fact, Scandinavian countries, which are well-known for their egalitarian social systems, fare very high in the ranking, with Iceland ranking the second, Norway the 11th, Demark and Finland the 22nd and 23rd, respectively. At the bottom of the list, as expected, are mostly low-income African countries. As depicted in Figure 6, overall there is a pattern that countries of low adjusted average AAD tend to have higher AAD Gini. Notwithstanding, the wide dispersion of the scatter plot speaks strongly of the importance of accounting for both the average and the distribution of mortality risks in evaluating the wellbeing of a population. This is what sets AAD apart from life expectancy and infant mortality rate, which cannot explicitly provide a distributional measure of wellbeing on an individual basis.

Figure 7 is a scatter plot of the AAD Gini against the age-at-death Gini. It can be seen that age-at-death Gini grossly understate inequality, especially when inequality is relatively large. On average (median), it understates the level of inequality by 20 percent.

It has been discussed that as far as national adjusted average AAD and GDP per capita (PPP) are concerned, there is a positive, albeit non-linear, relationship between them. If the relationship holds at the individual level and individual income is sufficiently widely spread within countries, then the resulting national income Gini and the AAD Gini should be positively correlated. To examine this, we plot the two against each other in Figure 8. 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.

From Figure 8 it can be seen that, except for a few outliers, there is a recognizable positive relationship between the two Gini coefficients. The figure also shows that for a given value of income Gini, the value of the AAD Gini can vary over a range and vice versa, indicating that the mortality distribution captures some different information on welfare compared to income distribution. Due to the few outliers, the Spearman Rank Correlation and Pearson Correlation between the two Gini coefficients are equal to 0.67 and 0.61 only, as indicated in Table 4. Notwithstanding, caution should be exercised in drawing conclusions from these findings because the data on the income Gini, as explained previously, are far from uniform in terms of definitions and time periods. Further adding to this is the fact that income survey data are subject to much greater intended and unintended reporting errors than vital registration data.

5. Discussion

In this paper we advocated an improvement to current mortality-based measures of wellbeing and inequality using the concept of avoidable morality risks. A problem in using mortality data directly as a measure is that some mortality risks are natural or unavoidable and therefore bear no welfare implications. To obtain a meaningful measure of wellbeing, we need to separate avoidable and unavoidable mortality risks, and use only the avoidable one to construct the intended wellbeing measures. We proposed a simple data envelopment method to handle this issue. The method categorizes an observed death as either avoidable or unavoidable according to the probability that each scenario arises, rather than the actual cause of death. A merit of this probability based method is that it avoids the ambiguity and difficulty in the classification method.

The method was applied to year 2000 life tables of 191 countries to construct an age and gender specific unavoidable mortality risk profile for a hypothetical reference country. The mortality risks of the reference country are then used as a benchmark to discount the observed mortality of individual countries in deriving measures of avoidable mortality. Sensitivity tests indicated that the constructed distribution of unavoidable mortality risks is very robust to potential data errors in the life tables.

As an illustrative example, we apply the reference distribution of unavoidable mortality risk on the age-at-death measure to derive an improved measure – age-at-avoidable-death. It should be emphasized that the distortions in standard age-at-death measures are not constant, but changing with longevity. This implies that we cannot simply use mean difference in age-at-death as a method to control for unavoidable mortality risks. Similarly, we cannot address this problem by subtracting the age-at-death statistics of a benchmark country, say Japan, from those of another country as a measure of the latter country's wellbeing. This is because, while unavoidable mortality risks are supposed to be invariant across countries, they are age and gender specific. For instance, females are more prone to some types of cancers than males; lung development in infant males is slower than in females; and old bones break more easily than young bones. As a result, we have to control for unavoidable morality risks for each age and gender group individually before deriving the intended mortality statistics, as per the method employed here.

An appeal of AAD is that, like wealth-based measures, it provides a unified framework to measure both average wellbeing and inequality; at the same time, like other mortality-based measures, it can capture tangible as well as intangible attributes of wellbeing. Adjusted average AAD is also found to be closely tracking popular development indicators. Therefore, as an average wellbeing measure, adjusted average AAD is very consistent with other existing measures. On the other hand, AAD Gini provides very different pictures from age-at-death Gini and income Gini. The difference between AAD Gini and its age-at-death counterpart highlights the importance of accounting for avoidable deaths in using mortality for inequality measures. Examining the relationship between AAD Gini and income Gini is hindered by the lack of income Gini data, especially for developing countries. In our case, out of 191 countries only 77 have reliable income Gini data. This indeed presents an opportunity to use AAD Gini as a predictor of income Gini in the case of missing income inequality data. This opportunity is made possible by the fact that

AAD Gini and income Gini have a recognizable positive relation even before controlling for other factors, such as average income and population growth rate.

The paper has adequately demonstrated the feasibility and applicability of the concept of avoidable mortality risks in comparing levels and inequality in the distribution of wellbeing. As mortality data are more readily available and are often considered more reliable than income data, the proposed measures of average age-at-avoidable-death and the associated Gini inequality measure provide an excellent basis for cross country comparisons of wellbeing.

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Table 1 Mortality Profile of the Reference Country: Male Population

Lower bound age of the age group	**Country**[1]	**Conditional probability of dying**	**Life expectancy**[2]
0	Singapore	0.00373	79.36
1	Sweden	0.00052	78.66
5	Malta	0.00037	74.70
10	Estonia	0.00054	69.72
15	Iceland	0.00164	64.76
20	Malta	0.00239	59.86
25	San Marino	0.00300	55.00
30	San Marino	0.00319	50.16
35	San Marino	0.00399	45.31
40	San Marino	0.00648	40.48
45	Iceland	0.00915	35.73
50	Iceland	0.01735	31.04
55	Sweden	0.03091	26.54
60	Sweden	0.05292	22.31
65	Switzerland	0.08612	18.41
70	Monaco	0.12906	14.91
75	Monaco	0.18951	11.75
80	Monaco	0.31792	8.92
85	Brunei Darussalam	0.43098	6.91
90	Brunei Darussalam	0.52386	5.25
95	Brunei Darussalam	0.67937	3.82
100	Brunei Darussalam	1	2.69

Note:

1. The column shows the country that determines the envelopment for a given age group.
2. 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

Lower bound age of the age group	Country	Conditional probability of dying	Life expectancy
0	Sweden	0.00282	85.55
1	Sweden	0.00046	84.79
5	Slovenia	0.00019	80.83
10	Cyprus	0.00039	75.84
15	Denmark	0.00092	70.87
20	Israel	0.00100	65.94
25	Sweden	0.00128	61.00
30	Sweden	0.00140	56.07
35	Malta	0.00235	51.15
40	San Marino	0.00349	46.26
45	San Marino	0.00558	41.42
50	San Marino	0.00747	36.64
55	Andorra	0.01307	31.89
60	Andorra	0.02177	27.28
65	Japan	0.03440	22.83
70	Japan	0.05825	18.56
75	Monaco	0.10224	14.55
80	Japan	0.20225	10.92
85	Monaco	0.31431	8.06
90	Antigua and Barbuda	0.48322	5.61
95	Grenada	0.66230	3.98
100	Grenada	1	2.86

Notes as for Table 1.

Table 3

Top and Bottom Ten Countries in terms of National Average AAD

Country	National average AAD	Percentage of avoidable deaths
Top Ten		
Sweden	80.80	22.42
San Marino	79.00	18.44
Iceland	78.98	22.19
Andorra	78.86	13.91
Greece	78.57	32.18
Israel	77.32	26.30
Cyprus	77.26	38.14
Norway	77.22	27.09
Spain	77.15	24.53
Japan	77.14	8.76
Bottom Ten		
Burkina Faso	38.44	84.76
Niger	38.28	83.62
Lesotho	38.03	86.67
Central African Republic	37.71	86.02
Burundi	37.16	87.5
Zambia	36.03	89.23
Rwanda	35.98	88.54
Mozambique	35.22	88.97
Malawi	34.2	89.83
Sierra Leone	33.85	87.9

Table 4 Correlations between AAD Measures and Various Development Indicators

Development Indicators[1]	Adjusted average AAD		AAD Gini	
	Spearman Rank Correlation	Pearson Correlation	Spearman Rank Correlation	Pearson Correlation
Life expectancy	0.99	0.92		
GDP per capita	0.85	0.79		
HDI	0.91	0.90		
Income Gini			0.67	0.61

Notes:

1. The correlations between the development indicators are based on the list of countries for which data are available. The samples for life expectancy, GDP per capita, HDI, income Gini have 191, 159, 166, and 77 countries, respectively.

Figure 1 Conditional Probability of Death at Age x

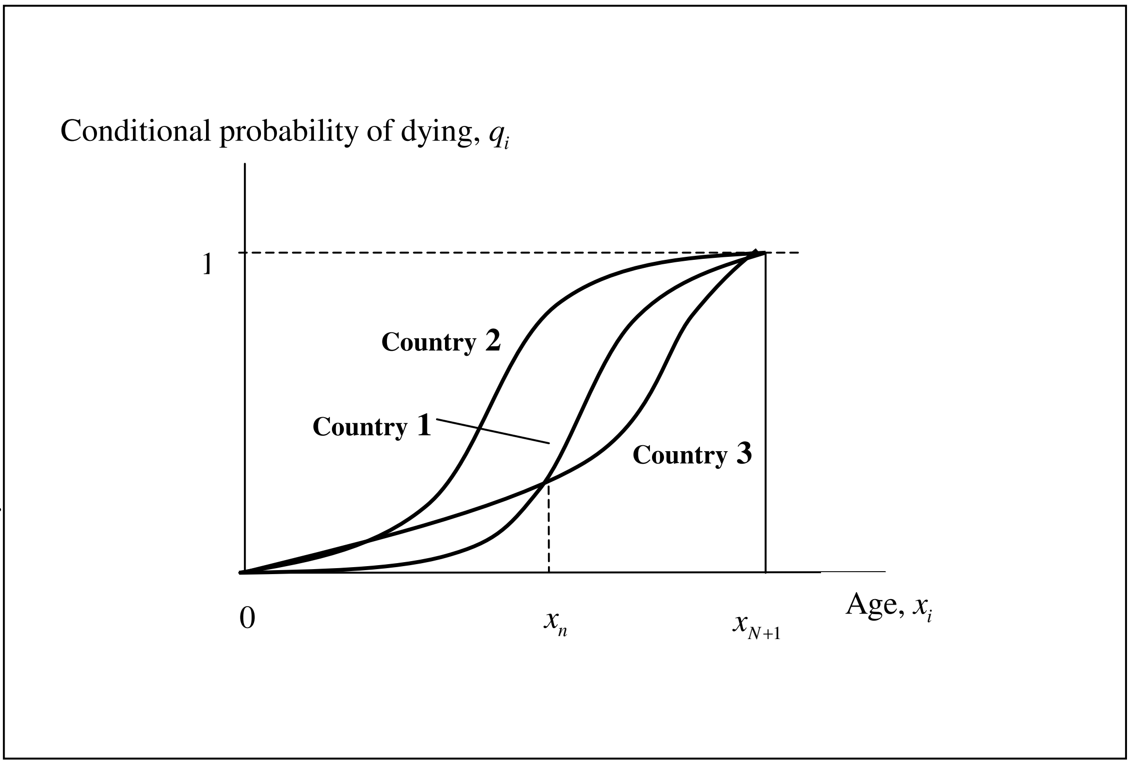


Figure 2 Average AAD and Proportion of Avoidable Deaths

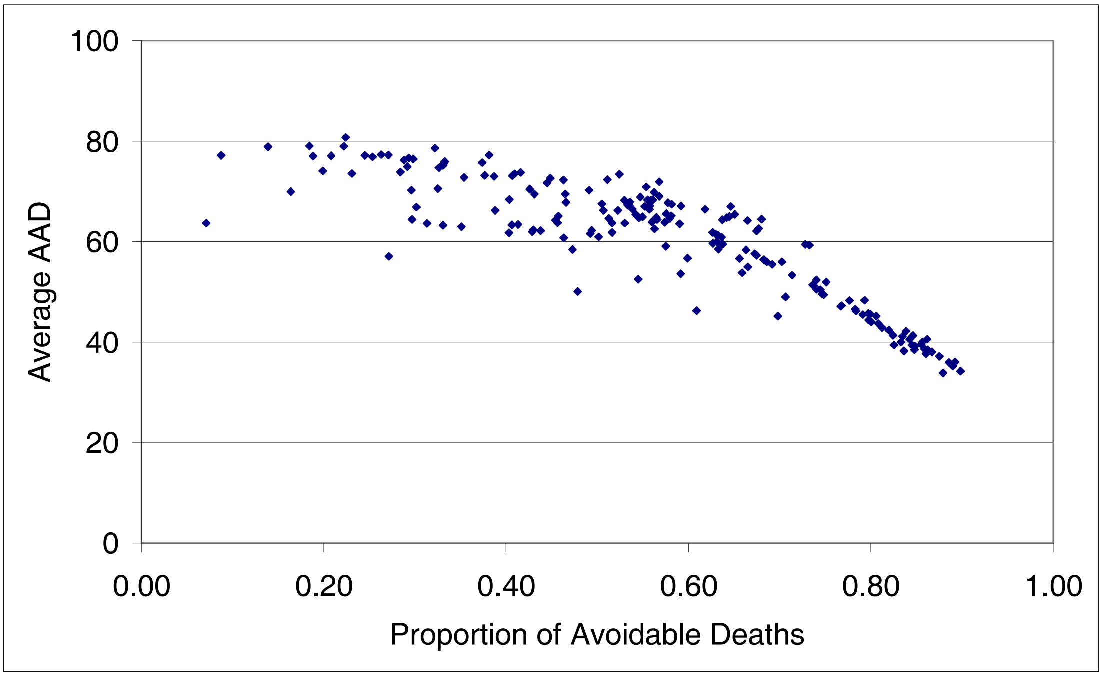
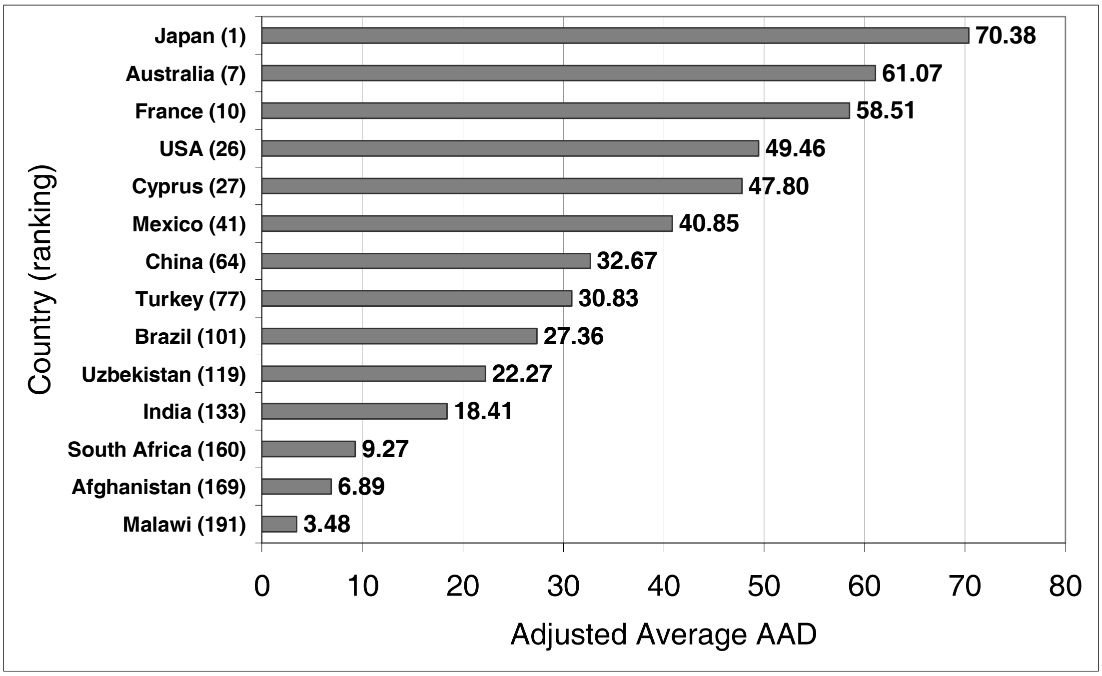


Figure 3 Ranking of Selected Countries based on Adjusted Average AAD



Note: Figures in brackets are the rankings based on average AAD figures.

Figure 4 Adjusted Average AAD and Average Age-at-death

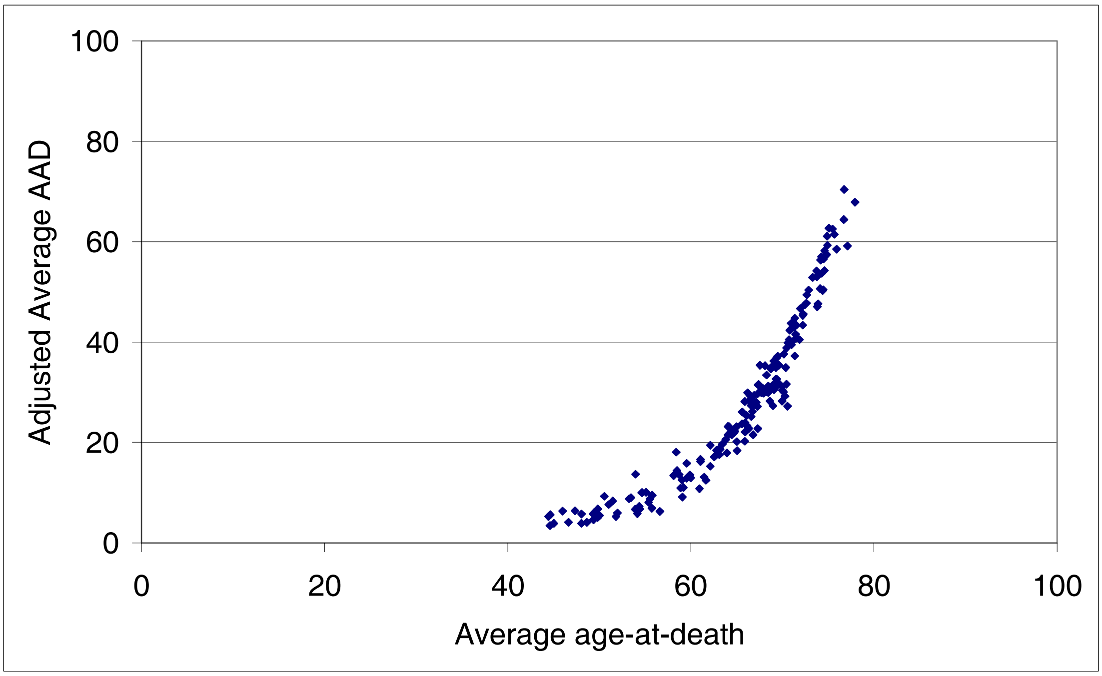
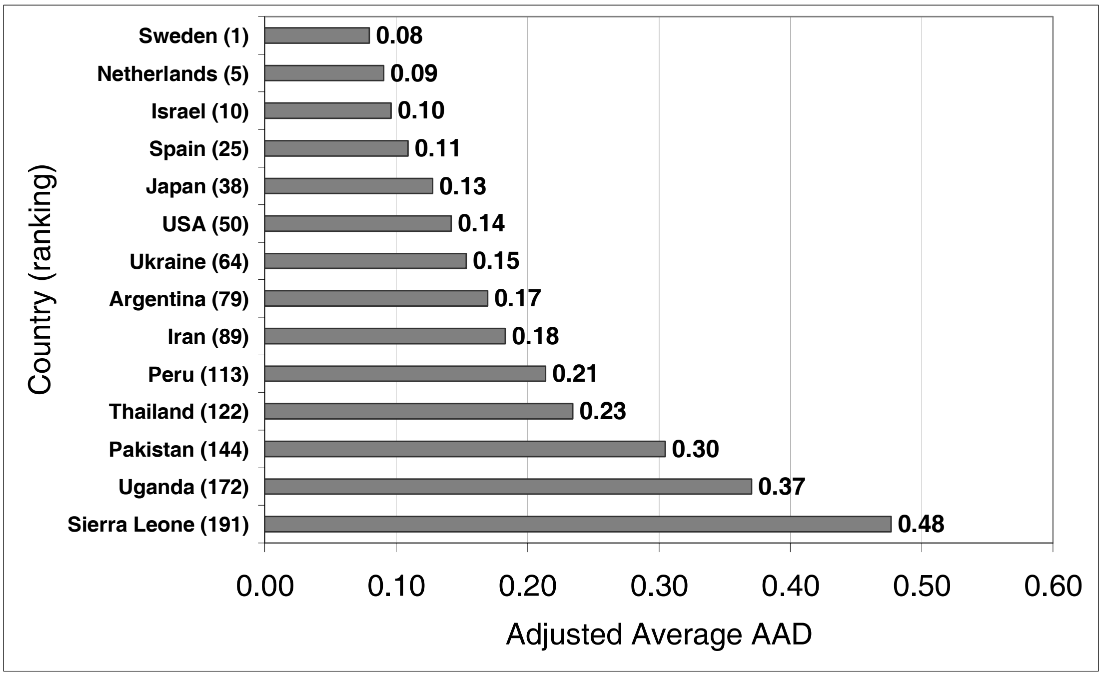


Figure 5 Ranking of Selected Countries based on AAD Gini



Note: Figures in brackets are the rankings based on AAD Gini figures.

Figure 6 AAD Gini and Adjusted Average AAD

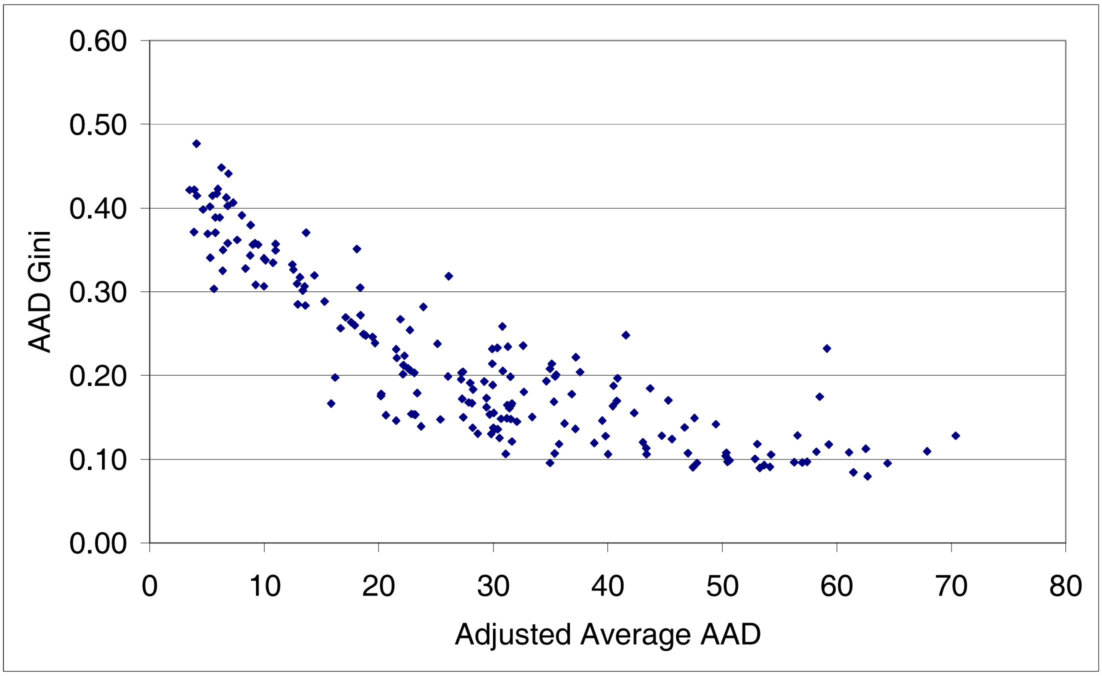


Figure 7 AAD Gini and Age-at-death Gini

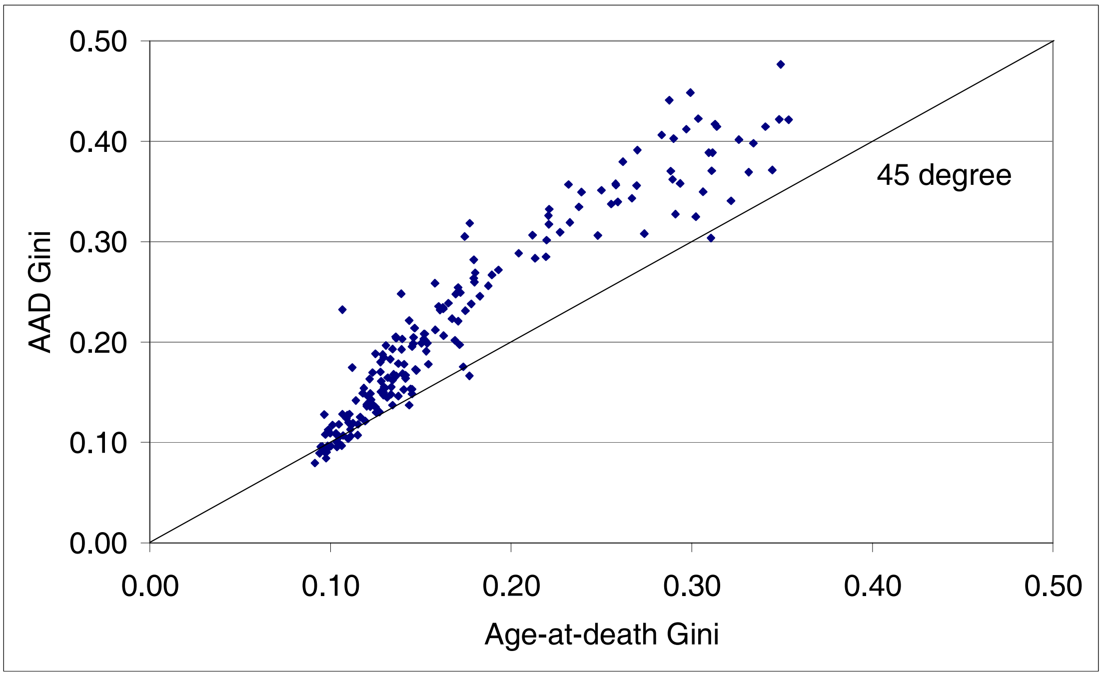


Figure 8 AAD Gini and Income Gini