Towards a Diversification of Causes of Deaths

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Short abstract

Lifespan inequalities have been decreasing since the 17th century in industrialized societies, as individuals became more homogeneous in their age at death. But are individuals also becoming more homogeneous in their cause of death? In this paper, the diversity of causes of death is studied using entropy measures. It is shown that, due to the major reductions in deaths from cardiovascular diseases, the share of a range of other causes of deaths, such as infectious diseases, mental and behavioral disorders and diseases of the nervous system, have been increasing in the last two decades in 16 low mortality countries. This redistribution of cardiovascular deaths towards many other causes is leading to a diversification of causes of death.

1 Introduction

Age and cause of death distributions have known major changes since the 17th century, leading to important improvements in life expectancy. These changes have been summarized in the epidemiological transition (Omran, 1971). The epidemiological transition hypothesis that all countries did or will go through three stages: 1) *Age of pestilence and famine*, characterized by high and fluctuating mortality dominated by infectious and parasitic diseases; 2)*Age of receding pandemics*, characterized by a decline in mortality, especially mortality due to infectious diseases; 3) *Age of degenerative and man-made diseases*, during which mortality reductions slow down and mortality is now dominated by degenerative and man-made diseases.

However, the progress in mortality reductions did not slow down in the *Age of degenerative and man-made diseases* in many industrialized countries, as theorized by Omran (1971), due to important reductions from cardiovascular mortality. The cardiovascular revolution has led to further improvement in life expectancy and brought Olshansky and Ault (1986) to suggest a fourth stage: *Age of delayed degenerative diseases*. In the fourth stage, the major causes of death present in the third stage remain the main "killers" but the risks of dying from these diseases are shifted towards older ages. It is thus hypothesized by Olshansky and Ault (1986) that the causes of death distribution should remain similar over time, but the age distribution of deaths will be shifted towards older ages.

The shift in the age distribution of death towards older ages is now well documented (Bongaarts, 2005; Canudas-Romo, 2008, 2010; Cheung and Robine, 2007; Vaupel and Gowan, 1986), and is known as shifting mortality or postponement of mortality. Progress in life expectancy since the 1960s has been mainly attributed to shifting mortality in low mortality countries (Bergeron-Boucher et al., 2015). However, the cause of death distribution did not remain unchanged in these countries. While the leading causes of death are still degenerative, the share of each cause of death is changing. Bergeron-Boucher et al. (2017) showed that heart diseases represented over 40% of the deaths among Canadians aged 65 years and older in 1979, but only 21% in 2011. In England, the most common cause of death for females was dementia and

Alzheimer's disease in 2016, representing 15.8% of the deaths. Death rates from dementia and Alzheimer's disease overtook those of heart diseases in 2012 in England (Public Health England, 2018).

Bergeron-Boucher et al. (2017) noticed that while the share of deaths due to cardiovascular diseases were decreasing over time, the proportions of many other smaller causes of death were increasing. The authors then theorized that the important decrease in cardiovascular mortality leads to a diversification of causes of death. This finding is contradictory from the findings of Izsak (1986), which rather argued for a concentration of causes of death. It is here ask, are we heading towards a diversification or concentration of causes of death? The diversity of causes of deaths in 16 low mortality countries is studied using entropy measures.

2 Methods

Diversity of causes of death can be measured with the normalized Shannon entropy. The Shannon entropy (H) is a well-known measure of the diversity of a distribution. The more components there are and the more equally likely they are to occur, the higher H would be. However, as causes of death can be grouped in smaller or bigger groups of causes, often depending on the data available or the author's choice, I decided to normalize the entropy ($\hat{H}$). The entropy is normalized on the number of components (n) in the distribution.

$$\hat{H}_t = -\sum_{i=1}^{n} \frac{p(i)_t \, log(p(i)_t)}{log(n)} \tag{1}$$

$\hat{H}$ varies between 0 and 1. If $\hat{H} = 0$, all deaths would be concentrated in one cause and if $\hat{H} = 1$, the deaths are equally distributed across the causes suggesting a higher diversity.

The Kullback-Leibler (KL) divergence can be used to study the component-specific changes between two distributions, i.e. changes in the cause-specific proportions between two consecutive years. The KL divergence is the difference between the log-transformed proportion p of component i of two distributions (at time t and $t+1$), weighted by the importance of $p(i)_t$.

$$KL(i)_{t:t+1} = p(i)_t \, log\Big(\frac{p(i)_t}{p(i)_{t+1}}\Big) \tag{2}$$

A negative KL is interpreted as a decrease in the component's share over time and a positive KL represents an increase.

3 Data

We use data from the WHO Mortality Database (WHO, 2018). We extracted data by cause of death for females and males in 16 low mortality countries: Australia, Belgium, Canada, Denmark, Finland, France, Germany, Italy, Japan, the Netherlands, New Zealand, Norway, Spain, Sweden, United Kingdom and the United States. Only data classified under the 10th revision of the International Classification of Disease (ICD-10) were used, to avoid discontinuities in the time-series caused by the change of ICD revisions (Meslé and Vallin, 2008). The year each country started using the ICD-10 varies from 1994 (Denmark) to 2003 (Italy).

The deaths are classified by the main ICD-10 chapters: certain infectious and parasitic diseases (Ch1), neoplasms (Ch2), diseases of the blood and disorders of immune mechanism (Ch3), endocrine, nutritional and metabolic diseases (Ch4), mental and behavioural disorders (Ch5), diseases of the nervous system (Ch6), diseases of the eye and adnexa (Ch7), diseases of the ear and mastoid process (Ch8), diseases of the circulatory system (Ch9), diseases of the respiratory system (Ch10), diseases of the digestive system (Ch11), diseases of the skin and subcutaneous tissue (Ch12), diseases of the musculoskeletal system and connective tissue (Ch13), diseases of the genitourinary system (Ch14), pregnancy, childbirth and the puerperium (Ch15), conditions originating in the perinatal period (Ch16), congenital malformations, deformations and abnormalities (Ch17), symptoms, signs and abnormal clinical and laboratory findings (ill-defined) (Ch18), and external causes of morbidity and mortality (Ch20).

4 Results

Figure 1 shows $\hat{H}$ for females and males in 16 low mortality countries between 1994 and 2016. With the unique exception of Finnish females, all countries and both sexes have known an increase in $\hat{H}$ in recent decades, meaning that the deaths are more and more equally distributed across causes. These results thus suggest that these countries are experiencing a diversification of causes of deaths.

To understand why this process occurs, Figure 2 shows the mean KL divergence over years by country and cause of death. The figure shows that the main difference in the causes of death distribution over time comes from a decrease in the share of deaths from cardiovascular diseases (Ch9). Deaths due to cardiovascular diseases represented between 26% (French males) and 52% (English women) of the total number of deaths in 2003. In 2013, these proportions dropped to 22% (French males) and 43% (English women). This decrease led to an increase in the share of deaths of many other causes – Ch1, Ch2, Ch3, Ch4 (mainly males), Ch5, Ch6, Ch7, Ch8, Ch10 (mainly females), Ch12, Ch13, Ch14, Ch15, Ch18 and Ch20 (mainly females) – for most countries.

However, deaths are not equally redistributed from cardiovascular diseases towards the remaining causes. In particular, mental and behavioral disorders (Ch5) and diseases of the nervous system (Ch6) tend to take a relatively bigger share, followed by neoplasms (Ch2) and ill defined causes (Ch18). Certain infectious and parasitic diseases (Ch1), endocrine, nutritional and metabolic diseases (Ch4), diseases of the respiratory system (Ch10) and diseases of the genitourinary system (Ch14) also tend to have a more important positive KL measure than other causes. This redistribution of deaths from one dominant cause to many others is responsible for the diversification of causes observed in Figure 1.

5 Discussion

This paper shows that low mortality countries are heading towards an increasingly important diversification of causes of death. This diversification could be the result of an aging population and the increase in life expectancy. As individuals reach older and older ages, they become increasingly vulnerable to multiple diseases. Aging is the strongest risk factor for many chronic diseases, most probably reflecting the long-term accumulation of unrepaired damages and dysregulation of many organ systems (Fabbri et al., 2015; Horiuchi, 2006). Aging also comes with increasing multimorbidities (Barnett et al., 2012; Fabbri et al., 2015), suggesting a higher competing risk between diseases to be the cause of death. A complementary explanation to aging

could be that even if multimorbidities might have always been present, they were less reflected in mortality analysis due to the high cardiovascular mortality, seizing most of the deaths. With the decline in cardiovascular mortality, the multimorbidities can be revealed in causes of death analysis.

Mortality risks from cardiovascular diseases did not shift towards older ages, as suggested by Olshansky and Ault (1986). Instead, the mortality risks from these diseases are decreasing at all ages for most low mortality countries (Peeters et al., 2011; Vallin and Meslé, 2004). Individuals "saved" from cardiovascular diseases thus tend to die from either other comorbid conditions or other diseases developing at older ages.

The diversification of causes of death could have implications for the future improvements in life expectancy. While increase in life expectancy since the 1960s was mainly driven by reductions from cardiovascular diseases (Vallin and Meslé, 2004), future improvements would require mortality reductions from a wider range of diseases. However, most deaths today are still from cardiovascular diseases (22 to 44%) and neoplasms (22 to 35%) and major improvements in life expectancy can still be archived by reducing mortality from these causes.

This paper shows that the causes of death distribution is still undergoing major changes. Individuals not only die at increasingly older and similar ages (Bergeron-Boucher et al., 2015; Cheung and Robine, 2007), but also from increasingly diverse causes.

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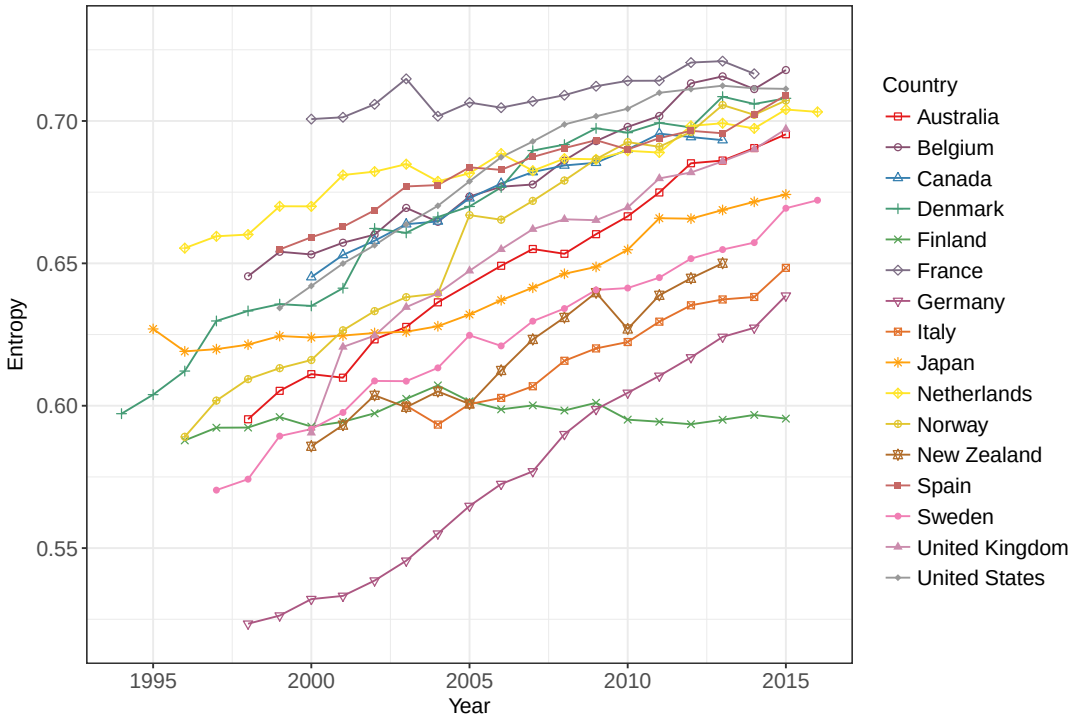
Figure 1: Normalized Shannon entropy of causes of death distributions for 16 low mortality countries, 1994-2016

(a) Females



(b) Males

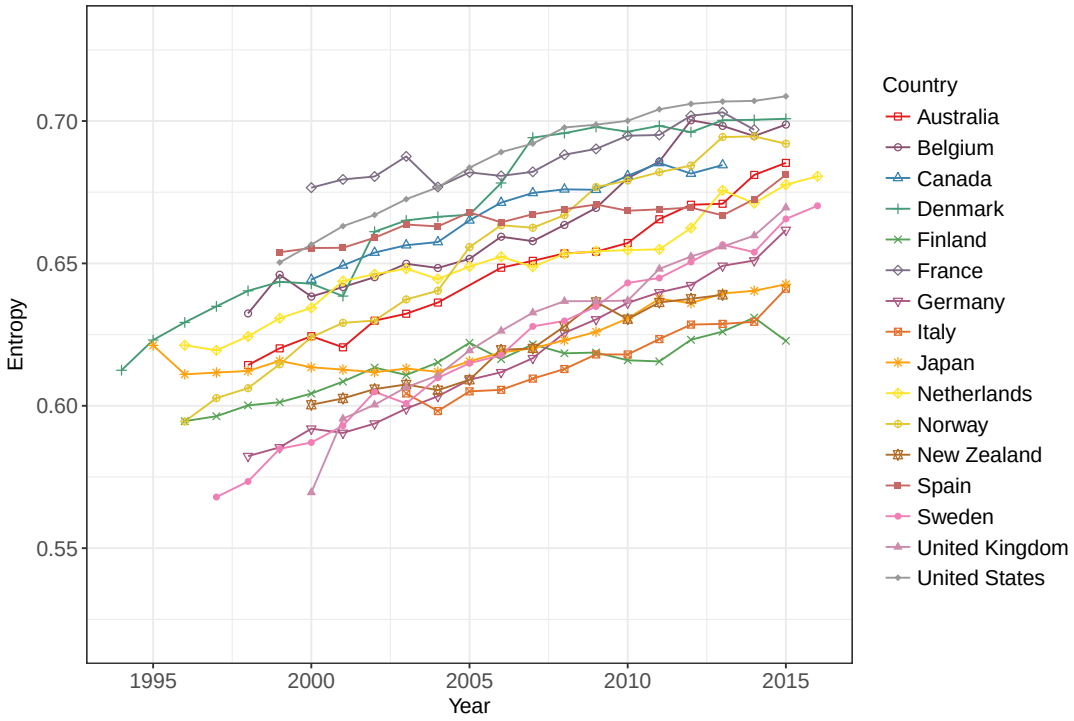
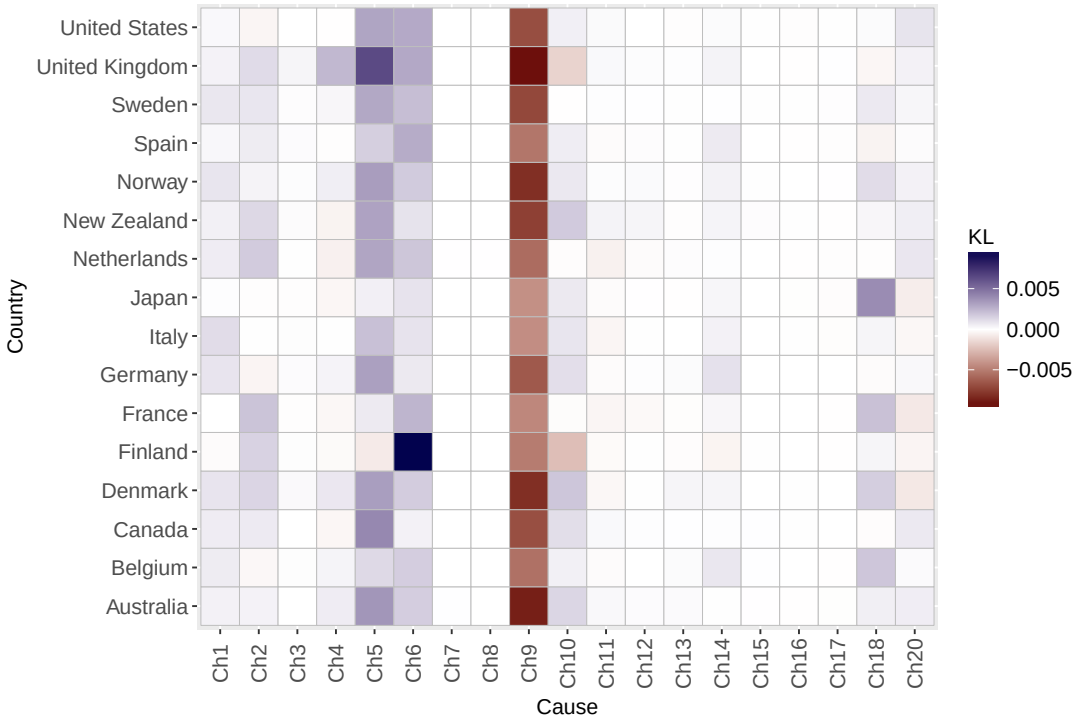


Figure 2: Kullback-Leibler (KL) divergence by cause of death for 16 low mortality countries, 1994-2016

(a) Females



(b) Males