Latin American convergence and divergence towards the mortality profiles of developed countries

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Abstract

Previous research argues that the world is converging to a single mortality regime. It is uncertain if Latin America and the Caribbean (LAC) are approaching such a regime. LAC have experienced major public health interventions aiming at universal healthcare coverage over the last three decades, and have experienced the highest number of homicides in the world. However, these interventions and homicide rates are not evenly shared between countries. Using data from the World Health Organization and United Nations, this study documents both, trends in life expectancy and lifespan variability from LAC. We analysed causes amenable to healthcare and external mortality for 20 countries between 2000 and 2014. By extending a previous method, we decompose the difference in lifespan variability between LAC and a developed-world benchmark into cause-specific spread, allocation, timing and joint effects. We determine which LAC countries and to what extent they are converging towards a developed regime. For both sexes, dispersion of amenable diseases through the age span largely contributes to the gap between LAC and the developed world. Additionally for males, the concentration of homicides, accidents and suicides in mid-life years further impede mortality convergence. Great disparity exists in the region. While some countries such as Cuba, Chile and Uruguay approach rapidly the developed regime, others such as Bolivia, El Salvador and Haiti remain far behind and suffer a clear disadvantage in terms of population health. Documenting differences in lifespan variability in LAC, alongside life expectancy, contributes to our understanding of inequality of lifespan and convergence/divergence processes across countries from this region.

Keywords: Lifespan variability, amenable mortality, external mortality, standard deviation decomposition.

1 Introduction

The epidemiological transition theory (Omran, 1971) is the starting point and obligatory reference of any global mortality convergence study. This theory accounts for a global mortality convergence towards a single mortality regime as part of changes in the dynamics of diseases and health. However, since its original publication, this theory has been much criticised. Olshansky and Ault (1986), for example, argued that the reduction of cardiovascular diseases was not anticipated and the role of the healthcare systems was omitted. In this regard, Frenk et al. (1991) demonstrated that, in the developing world, changes among epidemiological transition stages are not well defined and not all countries experience the same stages. They argued that changes in mortality patterns are given by an organized social response to health conditions within a framework of health transition. In this sense, Vallin and Meslé (2004) suggested a re-examination of the epidemiological transition theory, and integrated it as the first stage of a global process of health transitions.

During recent years, the study of mortality convergence has gained notable attention. For instance, Mayer-Foulkes (2001) argued that the convergence of life expectancies between nations is given in *convergence clubs*. These clubs are defined as large-scale clusters of countries with similar life expectancy trends over time. Bloom and Canning (2007) examined which *convergence clubs* have experienced larger increases in their life expectancies as of the decade

of 1960s. They found a general progress towards higher life expectancies, with a number of countries jumping from high-mortality to low-mortality clusters, mostly concentrated in developed countries. In the same line, Wilson (2011) suggested that a global demographic change has been taking place during the last century. He argued that inequalities between developed and developing countries lie on the different onsets of their transitions and on the speed of these demographic changes. Altogether, the findings of these studies suggest that the mortality gap between nations has been narrowing, and at the same time, population health among countries is converging towards similar regimes. This previous research, however, does not explain in detail the dynamics of mortality in Latin America and the Caribbean (LAC). Wilson (2011), for example, grouped the region in the *other developing countries* category without providing any further insight about this set of countries.

Some researchers have recently found evidence against mortality convergence and in support of prevailing health inequalities. Caselli et al. (2002), for instance, identified contradictions between the rapid increase of life expectancy observed in developed countries and the stagnation in developing nations. In their study, McMichael et al. (2004) pointed out that nations can be grouped into those that have shown rapid gains in life expectancy, those whose achieved gains are stagnating, and those in which the trends have reversed. It is not clear in which category LAC is included, since they only analysed a few countries, such as Chile, Mexico and Haiti, which do not fully represent the region. Features such as rapid gains in life expectancy and convergence towards developed countries were identified in Chile and Mexico from 1950 to 2000. However, this study did not address the recent stagnation of life expectancy in Mexico (Canudas-Romo et al., 2015). McMichael et al. (2004) also argued that the impediments of convergence are mainly due to inequalities between countries, stating that future health gains are not guaranteed by any deterministic process of convergence. Other studies show that among poor nations, development improves life expectancy more than it reduces infant mortality, whereas among wealthier nations, the situation is reversed (Clark, 2011). Further, Moser et al. (2005) indicated that since the late 1980s, the world has not only failed to become a more equal place in terms of mortality, but it has actually become less equal. In addition to this, Soares (2007) brought out evidence that communicable diseases have led to an increasing international inequality. He argues that reductions in mortality levels of developing countries require radical healthcare interventions. That once mortality attributable to communicable diseases has reduced, diffusion of the health transition may be accompanied by a long period of rising inequalities in life expectancy within and between countries.

Latin American mortality profiles

Researchers have situated most LAC countries in advanced stages of the epidemiological transition (Frenk et al., 1996). Child and infant mortality declined and reductions in adult mortality were observed as of the second half of the twentieth century. However, the region exhibited large heterogeneity. Countries like Argentina, Chile, Costa Rica, Cuba and Panama showed, since the decade of 1950s, a rapid progress towards the attainment of life expectancies at age 60 similar to developed nations (Palloni and Pinto-Aguirre, 2011). The downturn of infectious diseases and the stable trends of circulatory diseases are recognized to be the main reasons that contributed to these gains (Palloni and Pinto-Aguirre, 2011). Conversely, in other nations such as Haiti, the gap remains and even life expectancy decreases have occurred (McMichael et al., 2004). The prevalence of cardiovascular diseases has encouraged such trends. Diabetes has also made large contributions to the high mortality levels among men and women in LAC (Canudas-Romo et al., 2015; Klenk et al., 2016). Likewise, neoplasms have shown an upward trend in Bolivia, Ecuador, Guatemala, Nicaragua, Peru, Paraguay, El Salvador and Venezuela (Klenk et al., 2016). In addition to these issues, the region seems to be running into unprecedented obstacles. For instance, there is evidence that longevity in Mexico has recently stagnated due to the increasing violence and homicides prevailing in the country (Aburto et al., 2016). These phenomena seem to be replicating over the region since during recent years interpersonal violence has been an important contributor to the probability of death among men in Brazil, Colombia, El Salvador, Guatemala, Honduras and Venezuela, and to a lesser extent in Cuba, Costa Rica, Bolivia, and Peru (Naghavi et al., 2015).

Efforts from LAC governments to break mortality trends and improve health have been translated into several healthcare policies. In most LAC countries, social movements have contributed to healthcare system reforms. Conversely, in Colombia, Costa Rica and Mexico, the changing epidemiological profile was the main driver of these reforms (Atun et al., 2015). Major policy initiatives have focussed on improving maternal and infant health. In Argentina, since 2005, the Maternal and Child Health Insurance Program (*Plan Nacer*), provides access to basic health services for more than one

million previously uninsured pregnant women and children (WHO, 2013). In Guatemala, agreements established in 1997 between the government and NGOs have enabled basic healthcare and nutrition services to half of the rural population, focusing particularly on women and children (Dmytraczenko and Almeida, 2015). Most of the recent policy interventions in LAC aim for a universal coverage of basic healthcare services. Brazil, Chile and Mexico have made great strides towards this goal (WHO, 2010, 2013). In 2003, Mexico introduced a universal healthcare coverage scheme named Popular Health Insurance (*Seguro Popular*) (Frenk et al., 2006). This insurance package eliminated user fees and nowadays it covers over 50 million people (Knaul et al., 2012; Dmytraczenko and Almeida, 2015). Brazil and Cuba implemented tax-financed universal health systems. These policies were combined with interventions aimed at alleviating poverty and improving health access of the most disadvantaged populations (Atun et al., 2015). Chile and Costa Rica carried out strict initiatives in order to expand primary healthcare to the poor. These policies have brought positive results even in a context of slow economic growth, uneven income distribution and prevalent poverty (McGuire, 2001). In Chile, for example, as of 2005 the entire population has access to a basic health package guaranteeing treatments for up to 80 health conditions (Dmytraczenko and Almeida, 2015). In 1991, Colombia established the right to healthcare in its constitution. More than 20 years later, access to healthcare services in the country have improved considerably (Mesa-Lago, 2005; Atun et al., 2015). Other initiatives such as the *Conditional Cash Transfer* programs in LAC have also achieved positive results in enhancing population health. The Mexican *Progresa/Oportunidades*, the Brazilian *Bolsa Famila* and the Chilean *Chile Solidario* have been fighting poverty by increasing the income of the poor and, in consequence, improving their diet and health (Soares et al., 2010; Behrman and Parker, 2011).

In other countries, interventions to healthcare systems have been carried out to a lesser extent. Over the past two decades, Peru has made a major effort to expand health coverage, however, inequities remain in rural areas and among indigenous populations (Dmytraczenko and Almeida, 2015). Policies in Nicaragua and El Salvador have suffered only administrative changes by focusing on the allocation of the financial resources. In Honduras, the government implemented a program that focuses on the improvement of the nutrition of the population (Mesa-Lago, 2005). The government of Haiti lobbied for reform in 1996, however, it was not implemented due to a lack of financial resources. The reform to health-care policy in Venezuela has been stagnating for many years due to several political and social issues (Atun et al., 2015). Regrettably, these last nations have moved away from the achievement of universal healthcare coverage and instead, health inequalities within those populations have increased.

As we pointed out in paragraphs above, when studying mortality convergence in LAC, the picture sketched by researchers is less clear cut due to two main reasons. First, theories such as the epidemiological transition, are first conceived in the developed world and then extrapolated to developing countries. Thus, they might not be successful in explaining changes in health and mortality pathways in the developing world. Second, there is an apparent inconsistency between findings of previous research. On one hand, scholars argue the world is actually converging to a single demographic regime. On the other, recent studies show mixed results regarding narrowing the gap between mortality regimes.

Convergence: amenable mortality and variability of the age at death

Amenable mortality refers to those deaths from certain causes that should not occur in the presence of timely and effective healthcare (Nolte and McKee, 2004; Beltrán-Sánchez, 2011). Mortality from amenable conditions has declined in most developed countries but still represents a large share of their total mortality (Nolte and McKee, 2008). Likewise, diseases that have been pointed out to have a large effect on LAC mortality trends are considered amenable to healthcare. Mackenbach et al. (2013) argued that mortality levels from conditions amenable to healthcare are likely to reflect incidence and risk factors. However, in making cross-country comparisons they recommend to use the concept of amenable mortality as a crude indicator of the quality of medical care but not for routine surveillance of healthcare performance (Beltrán-Sánchez, 2011). Alternatively, the analysis of the timing and pace of mortality decline from amenable conditions may provide better indications of healthcare performance (Mackenbach et al., 2013). In this research we analyse the dynamics of amenable diseases in order to establish a link between changes in healthcare systems and mortality trends prevailing in the region. Further, this analysis allows us to identify how mortality convergence may results from improvements in healthcare.

The epidemiological transition theory (Omran, 1971) implies changes in death distributions from changing cause-of-death profiles associated with historical mortality declines. In his study, Robine (2001) redefined the phases of the epidemiological transition arguing that it can be seen through changes in lifespan variability: (1) The *Age of Pestilence and Famine* characterized by high mortality rates and high lifespan variability mainly driven by infectious diseases and a large number of deaths attributed to wars and famines. (2) The *Age of Receding Pandemics*, where the progressive changes in mortality distributions started. Child, infant and maternal mortality rates declined as a consequence of uneven and large decreases in malnutrition and infectious diseases resulting in large reductions of lifespan variability and sustained increases of life expectancy. (3) The *Age of Conquest of the Extent of Life*, based on the stage proposed by Olshansky and Ault (1986), where mortality declines in adult ages are more pronounced than at young ages, implying that increases in life expectancy are no longer associated with reductions in lifespan variability. In this phase, deaths are more concentrated at older ages, mainly attributed to cardiovascular diseases and cancers and originated in behavioural and lifestyle factors. Robine's analysis is remarkable since it links changes in age at death distributions with transition phases in a time-period basis. This assessment could not be possible by just examining the levels of mortality. In turn, his study highlights the need to give a look at lifespan variability in addition to the mean. Following Robine's approach, in this investigation we test out the universality of this convergence theory by looking at the average length of life and lifespan variation in LAC.

Researchers have studied lifespan variability using different indices such as life disparity (Vaupel and Canudas-Romo, 2003; Vaupel et al., 2011; van Raalte et al., 2014), Gini coefficient (Shkolnikov et al., 2003), conditional standard deviations (Edwards and Tuljapurkar, 2005), variance at age of death (Gillespie et al., 2014) and Keyfitz' entropy (Colchero et al., 2016; Fernandez and Beltrán-Sánchez, 2015). The high correlation between these indices (Wilmoth and Horiuchi, 1999; Vaupel et al., 2011) suggests that any of them can pick up the most general patterns in lifespan variability in inter-population comparisons (van Raalte and Caswell, 2013). Here, we use the standard deviation in age at death to assess lifespan variability. It is defined as the square root of the lifespan variance and it indicates how spread out the ages at death of a population are. The standard deviation is the preferred measure because is closely linked to the age slope of mortality. In consequence, differences in this measure are equivalent to discrepancies in the age slope of mortality schedules (Tuljapurkar and Edwards, 2011). In addition, we are able to compare life expectancy with standard deviation outcomes since both are expressed in years. The standard deviation is also appropriate for measuring inequality in health outcomes (Tuljapurkar, 2001). Although most dispersion indicators are sensitive to the age range studied, we decided to focus on the full age span to not overlook possible major improvements in very young ages that are more susceptible to public health interventions in LAC (Black et al., 2003; Elo et al., 2014).

In this research, differences between lifespan variability of developed and LAC countries are decomposed by extending the method introduced by Nau and Firebaugh (2012) to standard deviations. Here, the specific contribution of amenable diseases and external mortality to the overall variability are studied under the standard deviation decomposition method. This method determines *spread, allocation, timing* and *joint* components. *Spread* effects measure the heterogeneity of cause-specific age distributions. Since diseases prevail at different ages over the lifespan, variability of mortality distributions can be affected by how causes of death are allocated in a population. Thus, *allocation* effects account for differences in cause-specific death rates. *Timing* effects stand for inequalities between cause-specific mortality distributions due to different mean ages at death, in which the causes of death are centred. Finally, *joint* effects capture the part of the gap between standard deviations due to simultaneous differences in incidence and within cause-specific variability. By disentangling these effects we get insights into the actual sources of convergence/divergence and whether mortality is compressing or not.

This investigation addresses the following research question: To what extent the mortality levels of LAC countries are converging towards the levels encountered in developed countries? Particularly, given the major healthcare interventions in most LAC countries over the last decades, we hypothesize that amenable diseases to healthcare may have contributed to reducing lifespan variation and helped to converge towards a developed mortality profile, albeit with large heterogeneity between countries. We expect that healthcare improvements in LAC encourage reductions in spread and allocation effects of amenable diseases. Conversely, we hypothesize that the recent increase of homicide mortality in some of these countries could have enlarged the gap between LAC and a developed mortality regime via external mortality.

Finally, we scrutinize and quantify to what extent LAC mortality countries have converged towards a developed mortality schedule.

In the next section, an explanation of the data used in this research is provided. This is followed by a description of the extension of the decomposition method used in the analysis. Results are reported and the final section draws a discussion from the evidence presented.

2 Data and methods

In order to measure the existing gap between LAC and the developed world, it is necessary to set a reference point that depicts the mortality trajectories of the most developed nations. The United Nations created the Human Development Index (HDI), which measures the degree of development achieved by societies all over the world. The countries are classified according to three dimensions: education, economy and lifespan. Hence, countries that are ranked on the top positions of this index have exhibited the highest levels of human development. This index has been released every year since 1990. The countries that are ranked every year in the 95th percentile of the HDI since its creation are the ones included in the benchmark. By doing so, we are ensuring that these nations are the frontrunners in terms of human development. Thus, Australia, Canada, Denmark, Germany, Japan, Sweden, Switzerland, Norway, the Netherlands and the United States constitute our developed benchmark. Death counts by causes of death and exposures of these countries were added up in order to compute death rates and multi-decrement life tables.

We performed a sensitivity analysis by constructing an alternative version of the developed benchmark. From the original benchmark countries, we selected those that have also displayed the highest life expectancies in the world since 1990. Therefore, the alternative benchmark included just 5 countries: Australia, Canada, Japan, Sweden and Switzerland. This benchmark exhibited higher life expectancies and slightly lower standard deviations than the original, however, both trajectories were very much alike over time. The alternative benchmark returned similar results as those presented here, so we opted for the simplest selection of benchmark without the life expectancy restriction.

In this study we decomposed differences in life expectancies and in standard deviations. The decomposition of the gap in life expectancies by causes of death was performed using the method introduced by Arriaga (1984). Differences in standard deviations were disentangled with our extension of the decomposition method developed by Nau and Firebaugh (2012). Causes of death were grouped into three categories as follows: (1) causes amenable to healthcare (diseases stated in the classification introduced by Nolte and McKee (2008) plus cirrhosis and lung cancer), (2) external causes (homicides, suicide and accidents), and (3) all other causes of death. We included cirrhosis and lung cancer into the amenable to healthcare category because both are susceptible to medical treatments, public health interventions (e.g. prevention and taxation of alcohol and cigarettes), and to health behaviours. External causes were analysed separately because they are major causes of death in LAC countries (Naghavi et al., 2015; Briceño-León et al., 2008). Table A.1 details the specific International Classification of Diseases (ICD-10) codes of the causes of death included in this research.

Identifying the underlying cause of death is problematic at older ages due to many co-morbidities (Rosenberg, 1999). Many studies have looked at amenable mortality below age 75 arguing that medical care and policy interventions are likely to be most effective in saving lives at younger ages (Elo et al., 2014). We considered the complete age span when decomposing differences in standard deviations by the *spread*, *allocation*, *timing* and *joint* effects. We decided not to truncate the age at death distributions to any age because of two reasons. Firstly, truncating would heavily affect the right tale of the age at death distribution of our benchmark since in developed nations, the majority of deaths are currently concentrated at old ages and they are shifting towards even older ages (Canudas-Romo, 2008; Bergeron-Boucher et al., 2015). Secondly, LAC countries and the benchmark have different cause-specific age-profiles; thus truncating at an arbitrary age could return misleading or unequal comparisons. The benchmark represents a mortality profile that has been achieved elsewhere, so it is based on observed and attainable mortality levels. This means that our benchmark is a minimal representation of amenable/avoidable mortality which LAC could hypothetically attain. We performed a sensitivity analysis in order to consider the age dimension of the concept amenable mortality. In this analysis, amenable

deaths above age 75 were categorized as other causes of death. Therefore, differences in standard deviations were decomposed by the contribution each cause of death has over each age group (see figure 5 in Appendix for further details).

2.1 Data

The decomposition methods used in this research work with life tables. Multi-decrement life tables were computed for all LAC countries and for the benchmark over the period from 2000 to 2014. The retrieved data for each country considered in this study are detailed by 5-year periods, sex, and aggregated in 5-year age groups with an open age interval 85 and above. Datasets containing death counts by causes of death for all the countries come from the World Health Organization (WHO, 2017). In order to keep the comparability of mortality regimes among countries, only data coded under the ICD version 10 were used. However, not all the countries exhibit data coded under this version of the ICD over the same period of time. Table A.1 displays the specific time period used in this analysis for every country.

In addition to time data constraints, LAC region still suffers from problems of completeness. We mitigate this limitation by using death rates from the United Nations' World Population Prospects (United Nations, 2017); for death registration, United Nations (2016a) reported that most of LAC countries have at least 90% coverage. Further, we apply the cause of death distribution retrieved from WHO database to these death rates and computed multi decrement life tables following standard demographic techniques (Preston et al., 2000).

In order to use data with the highest data quality available, death rates for the benchmark countries were retrieved from the Human Mortality Database (Human Mortality Database, 2017). Both sources (United Nations and the Human Mortality Database) ensure the quality of the data by making consistency and completeness checks along with the national statistical institutes of such countries. Additionally, we performed robustness checks against the Latin American Mortality database (Palloni, A., Pinto, G. and Beltrán-Sánchez, 2014) by comparing death rates and life expectancies for every LAC country.

We can point out two limitations to this research. First, comorbidities among the elderly do not allow to disentangle the effect of amenable diseases at old ages. Extra sensitivity analysis was performed including and excluding the last open age-group, and the bias created from this is acknowledged here. Second, misreporting and misclassification of causes of death affecting the data quality of LAC countries. We tried to overcome this limitation by focusing only on the chapters of ICD-10 codes and considering just three broad groups of causes of death, assuming that the missing deaths (not registered) will be proportionally distributed among those correctly recorded.

2.2 Decomposition of the differences between standard deviations

Let l denote a LAC country with lifespan variance σ_l^2 and standard deviation σ_l. Analogously, b denotes the developed benchmark with lifespan variance σ_b^2 and standard deviation σ_b . Thus, we can express the difference between standard deviations as:

$$\begin{aligned} \sigma_l - \sigma_b &= \sqrt{\sigma_l^2} - \sqrt{\sigma_b^2} \\ &= \left(\frac{1}{\sqrt{\sigma_l^2} + \sqrt{\sigma_b^2}}\right)(\sigma_l^2 - \sigma_b^2). \end{aligned} \tag{1}$$

This result allow us to extend the Nau and Firebaugh (2012) decomposition method by expressing the difference between standard deviations in meaningful demographic terms as

$$\sigma_l - \sigma_b = spread + allocation + timing + joint, \tag{2}$$

Spread effects account for discrepancies in standard deviations due to cause-specific variability. *Allocation effects* capture differences in the number of deaths attributed to each cause of death. *Timing effects* stand for standard deviations inequalities due to different cause-specific mean ages of death. Finally, *joint effects* account for differences in standard deviations explained by the simultaneous interaction between allocation-spread and allocation timing terms. Positive (negative) values of any of these effects contribute to increase (decrease) the gap between LAC and the benchmark in lifespan variability. See Section A.1 in the Appendix for more details about the decomposition method.

Figure 1 about here

In most populations, spread, allocation and timing effects occur at the same time. Figure 1 illustrates such effects by comparing deaths attributed to external causes in Mexico versus the benchmark for the period 2010-2014. Panel A shows that in Mexico, external causes prevail in slightly broader age intervals than in the benchmark. These discrepancies are considered in the *spread* effect, which is 0.13 years in this case. The distribution of deaths is more peaked in Mexico than in the benchmark. This phenomenon is displayed on Panel B, which portrays the *allocation* effect (0.82 years). External-causes-specific mean age at death in the benchmark is around age 20 whereas for Mexico is age 30. The difference between means is captured by the *timing* effect on Panel C (-0.28 years).

3 Results

Tables 1 and 2 show the average and latest values for life expectancy and lifespan variability for all LAC countries for females and males, respectively. Note that the years considered in these calculations differ from country to country since data are not available during the same periods of time for all the countries. Detail information about the specific years analysed for each country can be found on Table A.1. Standard deviations are in general low for countries with high life expectancies. Chile, Costa Rica, Cuba and Uruguay, for example, exhibit the highest life expectancies and the lowest lifespan variability of the region. Female and male populations from Mexico and Panama exhibit relatively high life expectancies in comparison with other countries in the region, but at the same time, they show higher lifespan variability than those countries with similar life expectancies. Conversely, Argentina and Costa Rica have attained standard deviations very much alike but their male life expectancies differ by 5 years.

We decomposed the differences in life expectancies between the benchmark and LAC countries by causes of death in order to measure the contribution of amenable diseases and external mortality. Calculations were performed for females (Table 1) and males (Table 2). Amenable mortality contributes more to the life expectancy gap among women than among men. The average share of amenable diseases is 4.11 years for females and 3.12 for males. Colombia, Dominican Republic, Guatemala, Haiti, Honduras, Mexico, Nicaragua, Paraguay, Peru and Venezuela exhibit the largest contributions of amenable diseases. Conversely, the proportion of external causes is higher among males than among females. The contribution of external mortality to the life expectancy gap is null (in average 0.01 years) for females and 0.8 years for males. Brazil, Colombia, Costa Rica, Dominican Republic, Ecuador, el Salvador, Mexico, Panama and Venezuela display high contributions of external causes to males' life expectancy gap, whereas Argentina and Cuba display the lowest.

Figure 2 shows a scatter plot of the differences between each LAC country and the benchmark for life expectancy (x-axis) and lifespan variability (y-axis) for females (panel *A.1*) and males (panel *B.1*). Panels *A.2* and *B.2* show life expectancy and lifespan variation level of the benchmark. Results show a strong correlation between differences in average length of life and differences in lifespan variability. That is, as life expectancy increases, lifespan variability decreases towards the benchmark level. However, substantial disparities between countries exist. Some populations exhibit large differences (e.g. Haiti and Bolivia with data available only for 2000-04 period, see Table A5 in the Appendix),

while others show values similar to the benchmark (e.g. Cuba). For instance, differences between female life expectancy in Chile, Costa Rica and Cuba with the benchmark are around two years, while the difference in standard deviation is around one year among these frontunners of longevity in the region. For males (Figure 2, panel B.1), the respective values for life expectancy differences are around one year, and half a year for standard deviations. Among the longevity laggards in the region and excluding Haiti and Bolivia, the largest differences for females are found in Paraguay and Honduras, whereas males from Guatemala and El Salvador exhibit the most distant values from the benchmark. Within the whole region, life expectancy differences range from 1 year to more than 20 years, while the standard deviation goes from half a year to almost 12 years.

During the period of study, the benchmark shows an increasing life expectancy with constant standard deviation. For females, (Figure 2, panel *A.2*) life expectancy went up by almost two years (from 81.61 to 83.39) while lifespan variability remained at around 14.40 years. Similarly, male life expectancy (Figure 2, panel *B.2*), changed from 75.85 years to 78.01 years, while the standard deviation took values around 15.90 years. This supports the finding that, over time, mortality in developed countries is shifting towards older ages.

Figure 2 about here

We next investigated how amenable diseases and external mortality affect lifespan variation. Figures 3 and 4 show the decomposition results for the difference between selected LAC countries and the benchmark in standard deviations in three periods (2000-04, 2005-09 and 2010-14) for females and males, respectively. Excluding Haiti and Bolivia due to poor data quality, we show results for these countries because they all represent different trajectories in LAC, see Tables A.3 and A.4 for detailed information of all countries. Each bar component is related to a decomposition effect (*spread*, *allocation*, *timing* and *joint*). Negative values indicate that the effect reduces the gap between the analysed LAC country and the benchmark. Values greater than zero increase the gap. The ten countries in Figures 3 and 4 display representative patterns identified in LAC.

Amenable diseases increase lifespan variation relative to the benchmark (panel *A* of Figures 3 and 4). This is mainly driven by spread effects that account for 60% of the gap, which means that amenable diseases are more age-dispersed in LAC than in the benchmark. For both, females and males the absolute impact of amenable diseases is similar. In countries such as Argentina, Chile, Brazil, Colombia, Costa Rica, Ecuador, El Salvador and Venezuela, spread effects have been reducing whereas allocation components have increased. This implies that in LAC, the number of deaths attributed to amenable diseases has gradually gone up and at the same time, compressed in narrower age intervals.These diseases are the largest contributors of the lifespan variability gap in infant and child mortality (ages between 0 and 5, see figure 5 in Appendix). Decreases in lifespan variability gap attributed to amenable diseases are more pronounced in Brazil and Ecuador than in the rest of the LAC populations where differences between standard deviations remained at similar levels over time.

Amenable diseases and external causes of death interact differently in making up the lifespan variability gap. While in females the contribution of external mortality is low, among males it accounts for a large share of the gap compared to the benchmark. In addition, large spread effects in amenable diseases contrasts with allocation components mainly observed in external causes. This could be explained by the fact that most external mortality is concentrated in mid-life years. The effect is concentrated in males from Brazil, Colombia, Ecuador, El Salvador, Venezuela and Mexico. Particularly external causes have a considerable impact in males from El Salvador and Colombia, where allocation effects are responsible for more than 2 years of the lifespan variability gap. Male life expectancies in Ecuador and Argentina are very similar over time, however, Ecuador exhibited standard deviations in average 4.4 years higher than Argentina. This implies that their mortality regimes are also very different. By decomposing the lifespan variability gap, we found that even though Ecuador has reduced spread effects of amenable diseases over time, these diseases are still more age dispersed in this country than in Argentina. Furthermore, Ecuador is strongly affected by external causes of death while Argentina is not. In Ecuador, allocation components of these causes are responsible for 1.5 years of male's lifespan variability gap.

Figures 3 and 4 about here

4 Discussion

The results derived from this research allowed us to analyse convergence trajectories and compare 20 countries from LAC with a constructed benchmark based on a developed mortality regime. By looking into lifespan variability, we were able to identify those countries that have continuously approached the developed-world mortality profile in the new century, and those that have experienced slow progress towards the benchmark with large disparities between LAC countries. Standard deviation is our preferred measure of lifespan variability because it is expressed in years, which allows direct comparisons with life expectancy outcomes. From our extension of the decomposition method by Nau and Firebaugh (2012) to standard deviation differences, we draw two important results: (1) dispersion of amenable diseases through the age-span still largely contributes to the gap between LAC and the developed world, and (2) the concentration of high levels of homicides, accidents and suicides in mid-life years are the main impediments for mortality convergence for males.

Overall, people in LAC live shorter lives and experience more uncertainty regarding their age at death than in the developed world. The gap in lifespan variability is mostly attributed to greater age-dispersion of amenable diseases in LAC than in the benchmark. Previous research on lifespan variability has shown similar patterns at the sub-national level. Lariscy et al. (2016) also found that most of the lifespan variance difference between Hispanics and Whites in the United States is due to large age dispersion (spread effects) of diseases. Despite the generalized mortality disadvantage of LAC, some countries such as Cuba, Chile, Uruguay, Costa Rica and Argentina have experienced a rapid progress over recent decades that has led them to achieve similar life expectancies and lifespan variability to those portrayed in the developed world. In particular, these countries have successfully reduced infant and child mortality (Naghavi et al., 2015), and show the lowest levels of violence in the region (Briceño-León et al., 2008). Improvements in amenable mortality are at the heart of this progress. Most health interventions such as vaccination programs, healthcare coverage and primary care are targeted to reduce mortality at very young ages (WHO, 2013). Moreover, these countries are the frontrunners of longevity in the region, with the lowest levels of lifespan variability as well. Among developed countries, a similar pattern has been found; the countries with highest life expectancy are usually the ones experiencing the lowest levels in variation of lifespans, due to progress on saving lives at younger ages (Vaupel et al., 2011). As a result, there is a strong negative association between life expectancy and lifespan variability (Edwards and Tuljapurkar, 2005; Smits and Monden, 2009), which is also supported by our findings.

Our results show that in countries such as Brazil, Colombia, Ecuador, El Salvador, Mexico and Venezuela, a strong component of external mortality exists. This contributes to the gap compared to the developed world. Although in some of these countries (e.g. Brazil, Colombia and Mexico) major efforts to achieve universal healthcare coverage have been made in the last decade (WHO, 2013), these efforts have been offset by the high levels of violence and homicides, particularly in men (Briceño-León et al., 2008). For instance, in Mexico, after six decades of continuous improvements, life expectancy stagnated in the first decade of the 2000's as a result of the burden of homicides and diabetes (Canudas-Romo et al., 2015). Moreover, the unexpected rise in homicides began in 2005, and in the next five years life expectancy decreased in most regions of the country (Aburto et al., 2016). Our findings indicate that several countries in the region are experiencing similar eroding effects caused by excess homicide mortality. Importantly, most of these deaths are concentrated in young ages (see figure 5 in Appendix), which greatly affect lifespan variability (Firebaugh et al., 2014; van Raalte et al., 2014; Aburto and van Raalte, 2017). Firebaugh et al. (2014) also found that allocation effects due to homicides largely contribute to the lifespan variability gap between Blacks and Whites in the United States. Therefore, reducing homicide rates among the Black population in the United States could lead to diminish the lifespan variability gap substantially. This conjecture could be extrapolated to the Latin American case; reducing homicides rates in these countries would lead to substantial gains in life expectancy accompanied by reductions in lifespan variability towards the developed mortality profile. There is no easy way to reduce violence and homicides in Latin America, and the consequences go beyond life expectancy and lifespan variability. Recent evidence suggests that the number of expected years to live in vulnerability related to violence has increased in the last decade in the Mexican population (Canudas-Romo et al., 2017). Similar consequences could be experienced in other countries. Our results provide definitive evidence that external mortality is a major public health issue in the region. Moreover, homicides, accidents and suicides are important

obstacles preventing most Latin American countries from converging towards a developed-world mortality regime.

The most disadvantaged countries in relation to the developed world are clearly Haiti and Bolivia. These nations experience the largest departures from the benchmark and have repetitively been pointed out as the most disadvantageous countries in LAC (Palloni and Pinto-Aguirre, 2011; McMichael et al., 2004). The high lifespan variability shown in these countries underscores the increasing heterogeneity in the region. From a public health perspective, our results are important because they disclose inequalities existent in these countries. These findings would have been overlooked by only focusing on life expectancy. Previous research has shown that most inequality in mortality is not between countries but within countries (Smits and Monden, 2009). Rise and stagnation in lifespan variability has been found in low socioeconomic groups of developed countries (van Raalte et al., 2014; Brønnum-Hansen, 2017; Sasson, 2016). In LAC, Bolivia and Haiti represent an example of this phenomena. Wilkinson and Pickett (2009) state that populations with more equal distribution of incomes have better health, fewer social problems such as violence, drug abuse, mental illness, obesity, and are more cohesive than ones in which the gap between the rich and poor is greater. Therefore, we speculate that the challenging task of reducing inequalities within Bolivia and Haiti and enhancing healthcare systems would help them to catch up with other countries from the region.

Inequality, development and the public health agenda

Latin America is the most unequal region of the world (Lustig et al., 2013). However, trends seem to be gradually changing. Income inequality has declined; for the region as a whole, the Gini coefficient declined from 0.55 in 2000 to 0.49 in 2012 (Lustig et al., 2013). Starting in 1990 and especially during the period between 2000 to 2014, health in LAC improved more quickly than did in income (de Andrade et al., 2015). In spite of these advancements, important health inequalities persist. LAC is facing growing challenges related to the predominance of non-communicable diseases and the resurge of some communicable diseases (Borges, 2017). External causes of death, driven by violent deaths and road traffic accidents, also play an important role in the complex and unequal epidemiological profile of LAC (de Andrade et al., 2015).

Human development in LAC has improved between 1980 and 2010 (United Nations, 2016b). According to the most recent Human Developed report (United Nations, 2016b), most of LAC countries display high human development. Chile and Argentina are the only nations in the region exhibiting very high levels development. In contrast, Paraguay, El Salvador, Bolivia, Nicaragua, Guatemala and Honduras show medium human development whereas Haiti displays the lowest levels in the region (United Nations, 2016b). Economic, health and human development inequalities are mirrored in mortality outcomes. Our results about lifespan variability reveal mortality inequalities within and between LAC countries but also in comparison to the developed world. Our mortality benchmark includes the most developed countries in the world in terms of longevity, education and standards of living. Therefore, by comparing LAC countries with such a benchmark, our analysis discloses links between development and mortality convergence; LAC countries that are closer to the benchmark levels show high development and low inequalities regarding the age at death, whereas the most disadvantaged countries in terms of development are the ones experiencing higher lifespan variability. Therefore, development seems to be the obvious and simplified solution to reduce inequalities and to achieve mortality convergence. However, as Gersh et al. (2010) point out, translating these outcomes into countries with limited resources and several public health issues is complex.

LAC countries have advanced many different approaches to healthcare system reforms such as controlling communicable diseases (Cuba), improving outcomes of early childhood (*Chile Crece Contigo* in Chile and *De Cero a Siempre* in Colombia) or alleviating poverty through conditional cash transfers (*Bolsa Familia* in Brazil). These programs have proven to be successful at improving health of Latin Americans (Atun et al., 2015). Some of these health reforms have been also successful in terms of mortality. For instance, the expansion of primary health care program in Brazil (*Estrategia de Saude de Familia*) triggered reductions in amenable mortality between racial groups (Hone et al., 2017). LAC governments have also made strong commitments to achieve universal healthcare coverage. According to Wagstaff et al. (2015), LAC countries may not have reached universal healthcare coverage yet; however, they are making great strides towards it. Brazil, Colombia, and Mexico are at the top levels of performance whereas Ecuador and Guatemala are at the bottom of them (Wagstaff et al., 2015). Most of universal healthcare programs in LAC are in the early stages

and it is premature to assess the full impact these policies have on the mortality trends.

This study brings new evidence that encourages the debate about the priorities of the public health agenda in LAC since the majority of countries seem to be immersed in a paradox. On the one hand, a lot of resources have been allocated to policies aiming for universal healthcare coverage (Frenk et al., 2006; Dmytraczenko and Almeida, 2015; Knaul et al., 2012) and to programs focused on the improvement of the general well-being of the LAC populations (Frenk et al., 2006; Behrman and Parker, 2011; Atun et al., 2015; Soares et al., 2010); on the other, violent and crime-related deaths prevailing in the region deteriorate health and shorten life expectancy of the Latin Americans (Jaitman, 2017). Keeping the former sustainable and eliminating the latter is indispensable for the improvement of health and well-being of LAC populations. Thus, local governments, NGOs, and other involved institutions need to balance out the allocation of resources in order to reduce inequality.

The nuanced convergence

Frenk et al. (1996) categorized LAC countries in four groups depending on the ratio of communicable to non-communicable diseases: (1) accelerated model (Argentina, Cuba and Uruguay), (2) countries that had a strong component of non-communicable diseases (Brazil, Chile, Colombia, Costa Rica, Panama and Venezuela), (3) late transitions (Dominican Republic, Ecuador and Mexico), and (4) dominated by communicable diseases (El Salvador, Guatemala and Peru). Patterns (3) and (4) do not fit any of the epidemiological models presented by Omran (1971). Instead, Frenk et al. (1996) argue that these countries fit well the *protracted-polarized model*, where communicable and non-communicable diseases coexist. In this model, phases of transition are immutable, which directly impacts mortality convergence of the region. The analysis of Frenk et al. (1996) was performed using data from the period 1959 to 1985. In recent years, new communicable diseases have appeared (e.g. Zika and HIV/AIDS), infectious and parasitic diseases such as cholera and dengue have resurged, and others like malaria, leprosy and leishmaniasis have intensified (Borges, 2017). These issues represent constraints to the transition phases of most LAC countries. A clear example is Brazil, where recent analysis have proven that this country has not followed any epidemiology transition model experienced by developed countries (Borges, 2017). In this sense. our findings echo previous research (Caselli et al., 2002; Vallin and Meslé, 2004) since the epidemiological transition (Omran, 1971) fails in explaining mortality and health changes in LAC. The dispersion of amenable diseases across the whole age span and the high prevalence of external causes at middle ages make it difficult to place LAC at any particular stage of the epidemiological transition (Omran, 1971). Thus, the double burden of amenable and external mortality in LAC can be better explained under a health transition setting (Frenk et al., 1991) since both issues are susceptible to public health interventions (Black et al., 2003; Elo et al., 2014).

Under a global perspective, our results reveal that the majority of LAC countries are converging towards mortality regimes of the developed world. During the first fifteen years of the 21st century, LAC has been approaching the *main sequence* of demographic transition (Wilson, 2011). However, the large heterogeneity between LAC countries and the prevailing inequalities at sub-national level disclose various nuances in the convergence. Following the idea of Mayer-Foulkes (2001) and Bloom and Canning (2007), we can distinguish four main convergence clusters within LAC: (1) the frontrunners (Argentina, Chile, Costa Rica, Cuba and Uruguay), (2) those nations mainly affected by amenable diseases with a low component of external mortality, (3) the LAC countries strongly affected by both external mortality and amenable diseases (Brazil, Colombia, Ecuador, El Salvador, Mexico and Venezuela), and finally (4) those nations lagging behind (Bolivia and Haiti). The (2) and (3) clusters include most of LAC populations and until now, these countries have displayed moderate convergence attributed to reductions in lifespan variability and gains in life expectancy. Nonetheless, the double burden of mortality in these countries represents an impediment to achieving further convergence since these issues are either, non-existent or with low impact in developed nations.

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5 Tables

Country	Country code	Life expectancy					Standard deviation		
		Average[a]	Latest value[b]	Difference[b, c]	Amenable diseases contribution[d]	External mortality contribution[d]	Average[a]	Latest value[b]	Difference[b,c]
Argentina	ARG	78.95	79.78	3.61	2.01	-0.08	16.64	16.46	2.12
Bolivia	BOL	64.25	64.25	17.36	2.61	-0.26	26.89	26.89	12.40
Brazil	BRA	76.64	78.31	5.09	3.58	0.13	18.27	17.79	3.45
Chile	CHL	80.75	81.28	2.12	1.22	-0.02	15.45	15.39	1.06
Colombia	COL	76.44	77.34	6.05	4.71	0.20	18.36	18.14	3.80
Costa Rica	CRI	80.85	81.64	1.76	1.69	-0.07	15.69	15.51	1.18
Cuba	CUB	80.33	81.23	2.16	2.62	-0.05	15.12	15.12	0.79
Dominican Republic	DOM	75.42	76.46	6.94	6.48	0.15	20.64	20.03	5.70
Ecuador	ECU	77.51	78.33	5.07	3.21	0.22	19.75	18.91	4.58
El Salvador	SLV	75.55	77.03	6.36	2.62	0.43	18.55	18.04	3.70
Guatemala	GTM	74.61	75.55	7.84	5.37	0.05	20.50	20.15	5.81
Haiti	HTI	60.11	60.11	21.50	8.61	0.00	26.37	26.37	11.88
Honduras	HND	74.89	75.36	8.04	6.65	0.02	21.88	21.72	7.39
Mexico	MEX	78.11	78.89	4.51	4.32	0.00	17.91	17.89	3.55
Nicaragua	NIC	75.69	77.43	5.96	5.96	0.00	19.76	19.13	4.79
Panama	PAN	79.34	80.44	2.95	2.98	-0.07	18.35	18.11	3.78
Paraguay	PRY	73.92	74.92	8.48	5.73	0.35	20.74	20.28	5.95
Peru	PER	75.67	76.83	6.56	5.45	0.01	19.61	19.01	4.67
Uruguay	URY	79.67	80.40	2.99	0.86	0.10	16.78	16.82	2.49
Venezuela	VEN	77.66	78.20	5.19	5.66	0.05	17.57	17.20	2.87
Benchmark[d]		82.54	83.39				14.44	14.34	

[a] Average values were calculated over the years in which data are available for the specific LAC country. Not all the countries exhibit data during the same years. Specific periods of time analysed for each country can be found on Table A.5.

[b] Calculations performed for the most recent period observed. Table A.5 displays information about the most period of time analysed for each country.

[c] Difference between the benchmark and the analysed LAC country in the most recent observed period.

[d] Contribution to the difference in life expectancy between the benchmark and the analysed LAC country in the most recent observed period. The decomposition of differences in life expectancy was based on the method introduced by Arriaga (1984).

[e] Includes information from Australia, Canada, Denmark, Germany, Japan, the Netherlands, Norway, Sweden, Switzerland and the United States.

Table 1: Life expectancies and standard deviations for Latin America and the Caribbean. Females, various years.

Country	Country code	Life expectancy					Standard deviation		
		Average[a]	Latest value[b]	Difference[b, c]	Amenable diseases contribution[d]	External mortality contribution[d]	Average[a]	Latest value[b]	Difference[b,c]
Argentina	ARG	71.34	72.11	5.95	2.72	0.15	17.89	17.77	1.95
Bolivia	BOL	60.03	60.03	15.82	1.85	-0.71	27.45	27.45	11.50
Brazil	BRA	69.12	70.95	7.12	2.98	1.78	20.86	20.17	4.35
Chile	CHL	75.22	76.11	1.96	0.83	0.26	16.84	16.40	0.58
Colombia	COL	69.12	70.15	7.91	3.28	3.17	22.14	21.92	6.10
Costa Rica	CRI	76.05	76.66	1.41	0.70	0.49	17.77	17.66	1.84
Cuba	CUB	76.32	77.06	1.01	1.19	0.00	16.36	16.29	0.47
Dominican Republic	DOM	69.15	70.16	7.91	4.87	1.81	22.76	22.14	6.32
Ecuador	ECU	71.69	72.78	5.29	1.79	1.51	22.33	21.46	5.64
El Salvador	SLV	66.40	67.85	10.22	2.67	3.98	22.62	22.37	6.55
Guatemala	GTM	68.20	69.18	8.88	3.83	1.35	23.00	22.75	6.93
Haiti	HTI	56.52	56.52	19.33	6.11	0.22	26.61	26.61	10.65
Honduras	HND	69.94	70.36	7.71	5.24	0.41	23.10	22.99	7.16
Mexico	MEX	73.24	74.01	4.06	3.20	0.73	20.37	20.32	4.50
Nicaragua	NIC	69.68	71.34	6.72	5.01	0.91	22.06	21.47	5.65
Panama	PAN	73.58	74.30	3.77	1.70	1.28	21.35	21.17	5.35
Paraguay	PRY	69.70	70.70	7.37	3.87	1.22	22.35	21.83	6.01
Peru	PER	70.35	71.54	6.52	4.47	0.06	21.30	20.66	4.84
Uruguay	URY	72.42	73.21	4.86	1.51	0.39	17.43	17.30	1.48
Venezuela	VEN	69.34	69.90	8.17	4.77	1.78	20.48	20.02	4.20
Benchmark[d]		76.98	78.07				15.93	15.82	

[a] Average values were calculated over the years in which data are available for the specific LAC country. Not all the countries exhibit data during the same years. Specific periods of time analysed for each country can be found on Table A.5.

[b] Calculations performed for the most recent period observed. Table A.5 displays information about the most recent period of time analysed for each country.

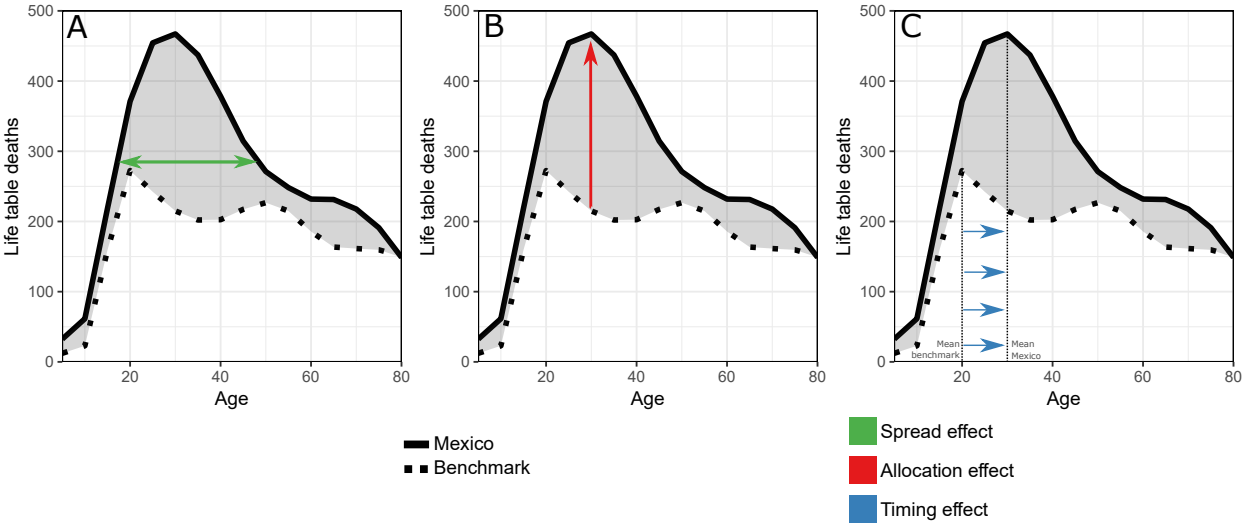
[c] Difference between the benchmark and the analysed LAC country in the most recent observed period.

[d] Contribution to the difference in life expectancy between the benchmark and the analysed LAC country in the most recent observed period. The decomposition of differences in life expectancy was based on the method introduced by Arriaga (1984).

[e] Includes information from Australia, Canada, Denmark, Germany, Japan, the Netherlands, Norway, Sweden, Switzerland and the United States.

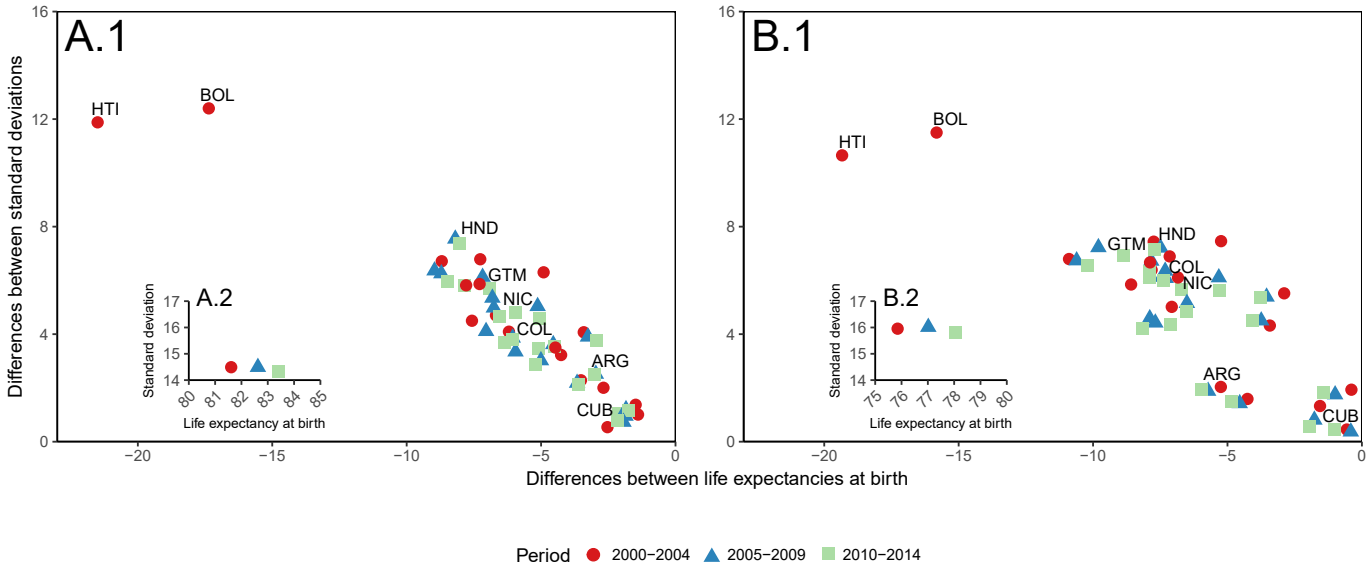
Table 2: Life expectancies and standard deviations for Latin America and the Caribbean. Males, various years.

6 Figures



Straight and dotted lines represent the number of life table deaths attributed to external causes of death in Mexico and the benchmark respectively for the period 2010-2014. The shaded grey area depicts the discrepancies between both mortality schedules. Decomposition effects are displayed on each panel.

Figure 1: Distribution of deaths attributed to external causes in Mexico versus the benchmark. Males, 2010-2014.



A.1 displays the differences for females and *B.1* for males. *A.2* and *B.2* show the trajectory of the benchmark for females and males respectively. Data for Bolivia and Haiti is only available for the period 2000-2004.

Figure 2: Scatterplot of standard deviation and life expectancy differences for Latin America and the Caribbean countries and the benchmark trajectory. Both sexes, 2000-2014.

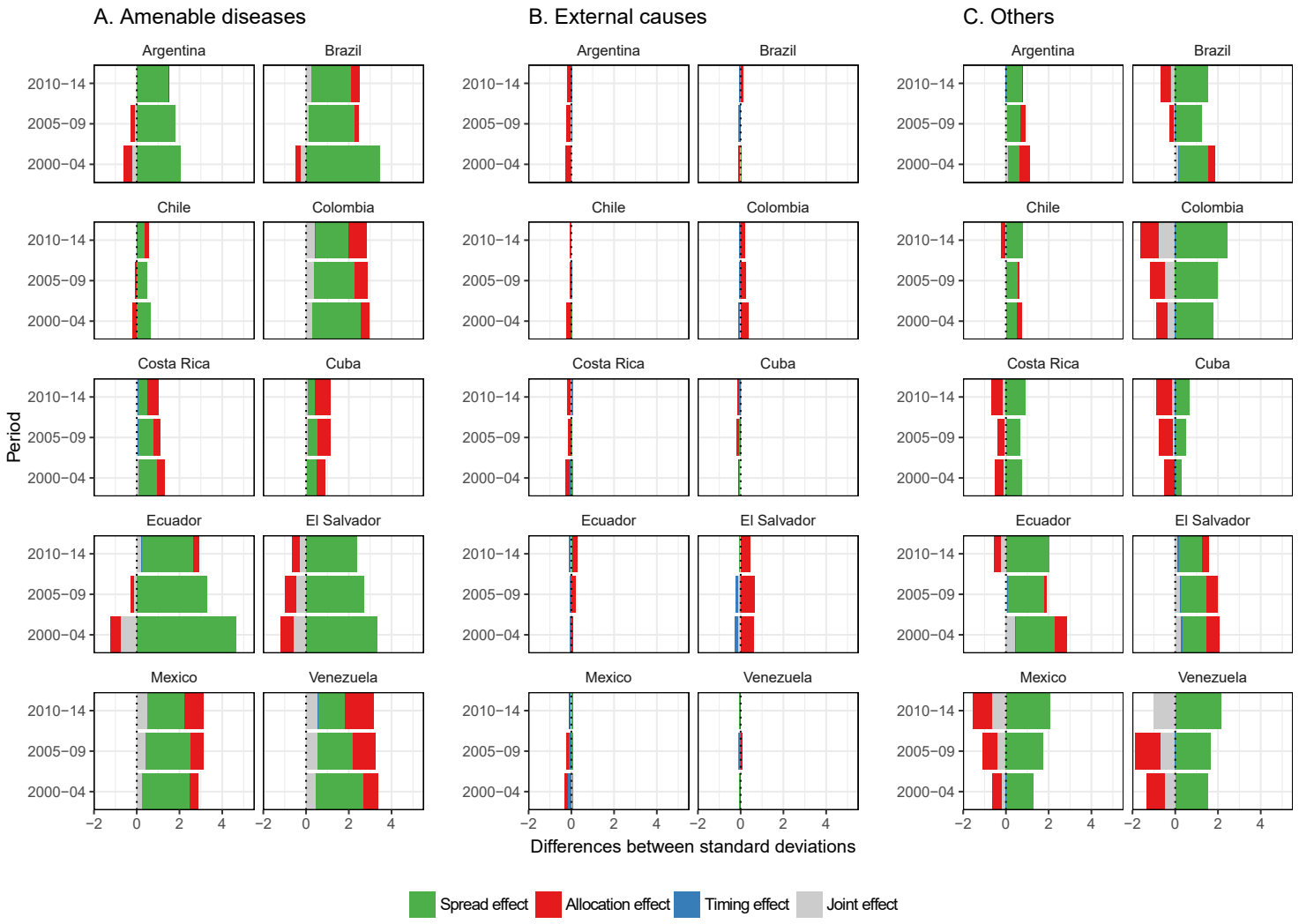


Figure 3: Decomposition of standard deviation differences for selected Latin America and the Caribbean countries. Females, 2000-2014.

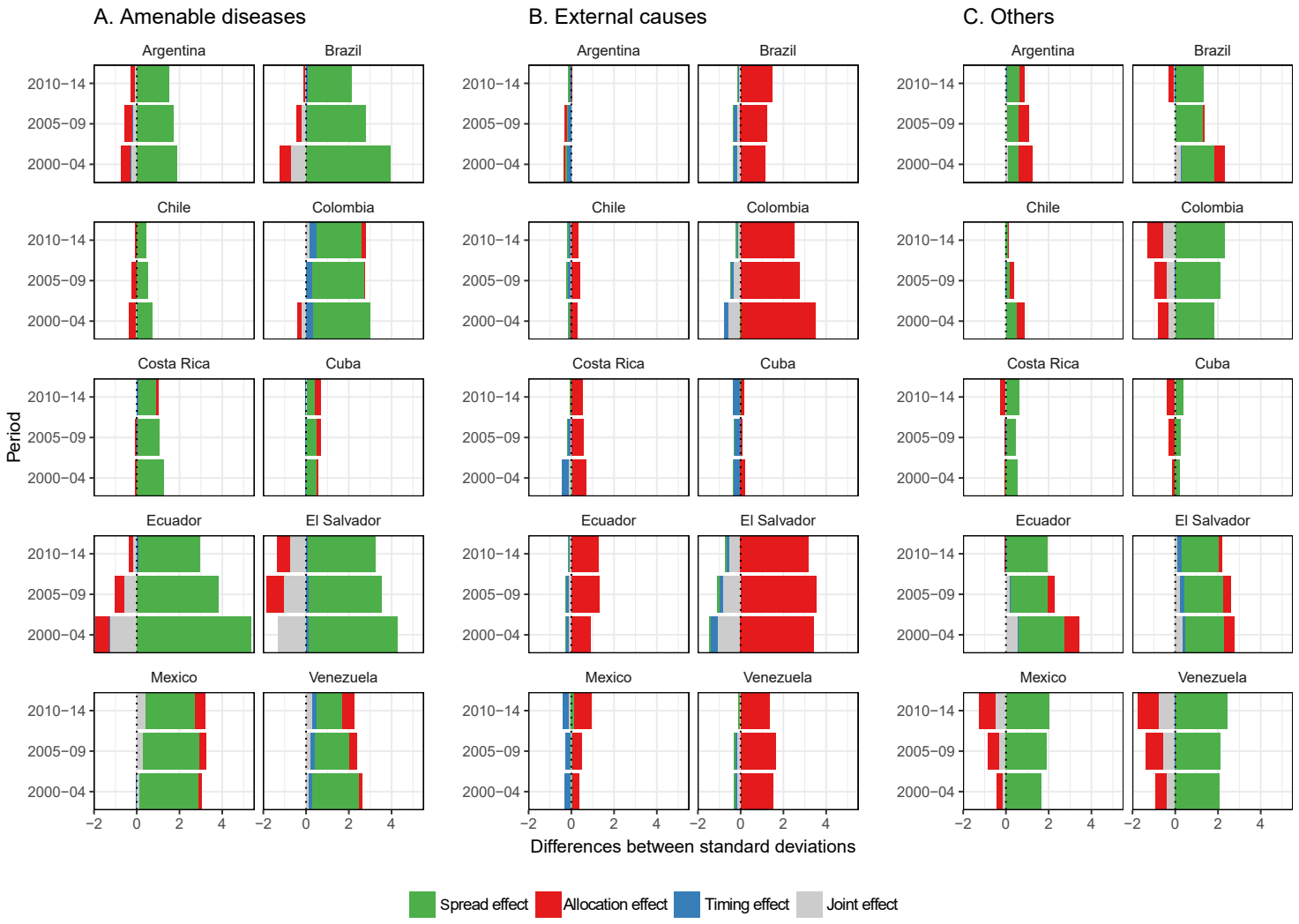


Figure 4: Decomposition of standard deviation differences for selected Latin America and the Caribbean countries. Males, 2000-2014.

A Appendix

A.1 Extension of the Nau and Firebaugh (2012) decomposition method to differences between standard deviations

Let N denote the total number of deaths in a population and N_c represent the number of deaths attributed to the cause c, with $c = 1, 2, ..., C$ mutually exclusive causes of death, such that $N = \sum_{c=1}^{C} N_c$. The age at death of the i-th individual that died by the c-th cause of death is denoted by $X_{c,i}$, such that $i = 1, 2, ..., N_c$. The mean age at death of the population is therefore given by $\bar{X}$, and $\bar{X}_c$ stands for the mean age of those deaths of the c-th cause. Thus, the lifespan variance (σ^2) of the population is defined as:

$$\sigma^2 = \sum_{c=1}^{C}\sum_{i=1}^{N_c} \frac{(X_{c,i} - \bar{X})^2}{N}, \tag{3}$$

and the cause-specific variance is

$$\sigma_c^2 = \sum_{i=1}^{N_c} \frac{(X_{c,i} - \bar{X}_c)^2}{N_c}. \tag{4}$$

Nau et al. (2012) introduced a novel method that decomposes the differences between lifespan variances. This method is based on the *analysis of variance* (ANOVA) models that account for the sources of variability. In this research, we extended this decomposition method by using the standard deviation of the age at death, which is defined as the square root of the lifespan variance ($\sigma \equiv \sqrt{\sigma^2}$).

Let l be a LAC country with lifespan variance σ_l^2 and standard deviation σ_l. Similarly, the benchmark that portrays the trajectories of the selected developed countries is represented by b. The difference between standard deviations is expressed as:

$$\begin{aligned} \sigma_l - \sigma_b &= \sqrt{\sigma_l^2} - \sqrt{\sigma_b^2} \\ &= \left(\frac{1}{\sqrt{\sigma_l^2} + \sqrt{\sigma_b^2}}\right)(\sigma_l^2 - \sigma_b^2). \end{aligned} \tag{5}$$

Thus, the difference in standard deviations reduces to an already known result for the difference in variances multiplying a factor as $\sigma_l - \sigma_b = K(\sigma_l^2 - \sigma_b^2)$, where $K = \frac{1}{\sqrt{\sigma_l^2} + \sqrt{\sigma_b^2}}$.

According to Nau et al. (2012), lifespan variances can be expressed as

$$\begin{aligned} \sigma^2 &= \sum_{c=1}^{C}\sum_{i=1}^{N_c} \frac{(X_{c,i} - \bar{X})^2}{N} \\ &= \sum_{c=1}^{C}\sum_{i=1}^{N_c} \frac{(X_{c,i} - \bar{X}_c)^2}{N} + \sum_{c=1}^{C}\sum_{i=1}^{N_c} \frac{(\bar{X}_c - \bar{X})^2}{N} \\ &= \sum_{c=1}^{C} p_c \sigma_c^2 + \sum_{c=1}^{C} p_c \bar{x}_c^2, \end{aligned} \tag{6}$$

where $p_c = \frac{N_c}{N}$ is the proportion of deaths of cause c among all deaths, such that $\sum_{c=1}^{C} p_c = 1$, and $\bar{x}_c^2 = (\bar{X}_c - \bar{X})^2$.

By combining the results derived in equations 5 and 6 the difference between two standard deviations is denoted as

$$\begin{aligned}
\sigma_l - \sigma_b &= K\left\{\sum_{c=1}^{C} p_{c,l}\sigma_{c,l}^2 - \sum_{c=1}^{C} p_{c,b}\sigma_{c,b}^2 + \sum_{c=1}^{C} p_{c,l}\bar{x}_{c,l}^2 - \sum_{c=1}^{C} p_{c,b}\bar{x}_{c,b}^2\right\} \\
&= K\left\{\sum_{c=1}^{C} p_{c,b}(\sigma_{c,l}^2 - \sigma_{c,b}^2) + \sum_{c=1}^{C} (p_{c,l} - p_{c,b})(\sigma_{c,b}^2 - \bar{x}_{c,b}^2) + \sum_{c=1}^{C} p_{c,b}(\bar{x}_{c,l}^2 - \bar{x}_{c,b}^2)\right. \\
&\left. + \sum_{c=1}^{C} (p_{c,l} - p_{c,b})[(\sigma_{c,l}^2 - \sigma_{c,b}^2) - (\bar{x}_{c,l}^2 - \bar{x}_{c,b}^2)]\right\}.
\end{aligned}$$

This equation can be rewritten in meaningful demographic terms as

$$\sigma_l - \sigma_b = spread + allocation + timing + joint, \tag{7}$$

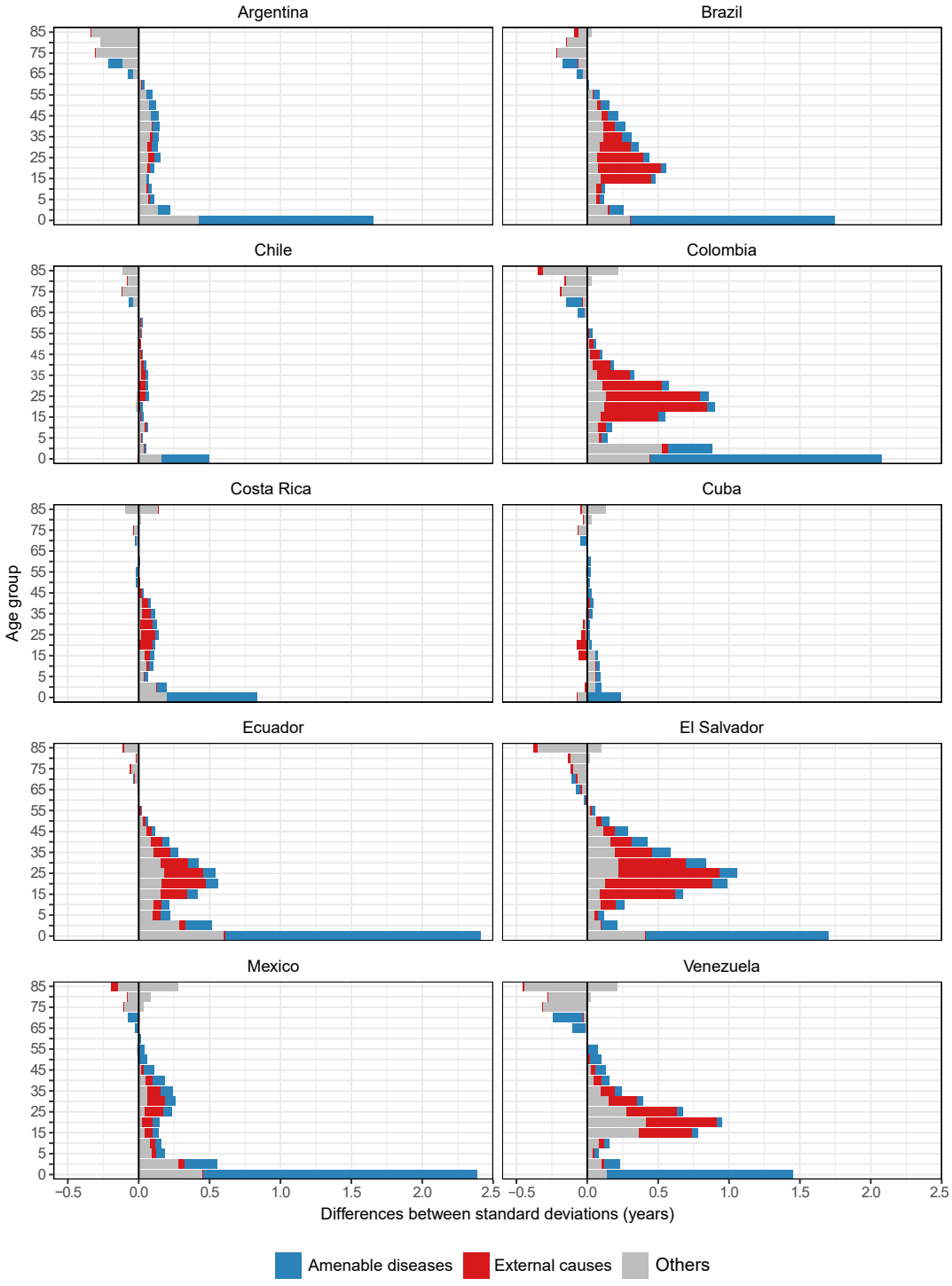
where these four effects are defined as:

$$spread = K\sum_{c=1}^{C} p_{c,b}(\sigma_{c,l}^2 - \sigma_{c,b}^2)$$

$$allocation = K\sum_{c=1}^{C} (p_{c,l} - p_{c,b})(\sigma_{c,b}^2 - \bar{x}_{c,b}^2)$$

$$timing = K\sum_{c=1}^{C} p_{c,b}(\bar{x}_{c,l}^2 - \bar{x}_{c,b}^2)$$

$$joint = K\sum_{c=1}^{C} (p_{c,l} - p_{c,b})[(\sigma_{c,l}^2 - \sigma_{c,b}^2) - (\bar{x}_{c,l}^2 - \bar{x}_{c,b}^2)].$$



Note: The decomposition was performed using the method introduced by Horiuchi et al. (2008)

Figure 5: Age-decomposition of standard deviation differences by causes of death for selected Latin America and the Caribbean countries. Males, 2010-2014.

Causes of death	**ICD-10 code**
Amenable diseases	
Intestinal infections	A00 - A09
Tuberculosis	A15-A19, B90
Other infections (Diphteria, Tetanus, Poliomyelitis)	A36, A35, A80
Whoopin cough	A37
Septicaemia	A40-A41
Measles	B05
Malignant neoplasams of colon and rectum	C18-C21
Malignant neoplasams of skin	C44
Malignant neoplasams of breast	C50
Malignant neoplasams of cervix	C53
Malignant neoplasams of cervix	C54, C55
Malignant neoplasams of tetis	C62
Hodgkin's disease	C81
Leukemia	C91-C95
Diseases of the thyroid	E00-E07
Diabetes mellitus	E10-E14
Epilepsy	G40-G41
Chronic rheumatic heart disease	I05-I09
Hypertensive disease	I10-I13, I15
Ischaemic heart disease	I20-I25
Carebrovascular disease	I60-I69
All respiratory diseases	J00-J09, J20-J99
Influenza	J10-J11
Pneumonia	J12-J18
Peptic ulcer	K25-K27
Appendicitis	K35-K38
Abdominal hernia	K40-K46
Cholelithiasis, cholecystitis	K80-K81
Nephritis and nephrosis	N00-N07, N17-N19, N25-N27
Benign prostatic hyperplasia	N40
Maternal deaths	O00-O99
Congenital cardiovascular anomalies	Q20-Q28
Perinatal deaths, all causes excluding stillbirths	P00-P96, A33, A34
Misadventures to patients during surgical and medical care	Y60-Y69, Y83-Y84
Lung cancer	C33, C34
Cirrhosis	K70
External causes of death	
Homicide	X85-Y09
Road traffic accidents	V01-V99
Suicide and self inflicted injuries	U03, X60-X84, Y87

Table A.1: International Classification of Diseases ICD-10 code of the causes of death included in this study.

Country	Life expectancy		Standard deviation	
	Average	Latest value	Average	Latest value
Females				
Australia	83.61	84.35	13.18	12.92
Canada	82.90	83.72	13.72	13.54
Denmark	80.80	82.11	13.33	12.91
Germany	82.19	82.85	12.88	12.64
Japan	85.81	86.39	12.76	12.52
The Netherlands	82.04	83.08	13.12	12.75
Norway	82.70	83.58	12.77	12.34
Sweden	82.98	83.68	12.41	12.15
Switzerland	83.91	84.69	12.71	12.26
United States	80.48	81.20	15.10	14.99
Benchmark	*82.54*	*83.39*	*14.44*	*14.34*
Males				
Australia	79.01	80.15	14.80	14.49
Canada	78.39	79.64	14.94	14.71
Denmark	76.44	78.05	14.35	13.86
Germany	76.79	77.88	14.42	14.09
Japan	79.08	79.93	14.21	13.90
The Netherlands	77.82	79.30	13.59	13.19
Norway	78.15	79.47	14.09	13.59
Sweden	78.90	79.94	13.54	13.31
Switzerland	79.11	80.44	14.23	13.62
United States	75.51	76.42	16.81	16.69
Benchmark	*76.98*	*78.07*	*15.93*	*15.82*

Note: All benchmark countries have data available for years 2000-2014.

Table A.2: Life expectancies and standard deviations for the countries included in the benchmark. Both sexes, 2000-2014.

	Amenable diseases					External causes of death					Others	Total[a]
Country	Allocation	Spread	Timing	Joint	Total[b]	Allocation	Spread	Timing	Joint	Total[b]		
Argentina	0.00	1.48	0.00	0.00	1.49	-0.17	-0.01	0.02	0.00	-0.17	0.81	2.12
Bolivia	-1.48	8.84	0.07	-5.22	2.21	-0.39	0.12	-0.11	-0.02	-0.38	10.57	12.40
Brazil	0.40	1.85	0.00	0.24	2.49	0.11	0.01	-0.04	-0.01	0.06	0.90	3.45
Chile	0.18	0.36	0.01	0.02	0.57	-0.07	-0.01	0.01	0.00	-0.07	0.55	1.06
Colombia	0.83	1.54	0.03	0.43	2.84	0.18	0.01	-0.04	-0.01	0.14	0.82	3.80
Costa Rica	0.53	0.42	0.01	0.07	1.03	-0.15	0.04	0.05	-0.02	-0.09	0.23	1.18
Cuba	0.72	0.36	0.00	0.08	1.16	-0.07	-0.02	-0.07	0.01	-0.15	-0.23	0.79
Dominican Republic	1.05	2.80	0.01	1.04	4.90	0.08	0.00	-0.03	-0.01	0.04	0.76	5.70
Ecuador	0.28	2.43	0.00	0.23	2.94	0.23	0.03	-0.08	-0.02	0.17	1.47	4.58
El Salvador	-0.36	2.37	0.02	-0.28	1.75	0.45	0.00	-0.04	-0.03	0.38	1.58	3.70
Guatemala	0.21	3.64	0.00	0.26	4.12	-0.04	0.02	-0.11	0.01	-0.13	1.66	5.65
Haiti	-0.70	7.91	0.00	-2.15	5.06	-0.11	0.05	-0.26	0.05	-0.27	7.10	11.88
Honduras	0.75	3.68	0.03	0.99	5.44	-0.07	0.10	-0.15	0.01	-0.11	1.91	7.23
Mexico	0.88	1.73	0.00	0.51	3.12	-0.02	0.05	-0.10	0.00	-0.07	0.50	3.55
Nicaragua	1.17	2.18	0.01	0.88	4.25	-0.10	0.02	0.01	-0.01	-0.07	0.61	4.79
Panama	0.74	1.71	0.01	0.42	2.88	-0.13	0.01	-0.02	0.00	-0.13	1.03	3.78
Paraguay	0.38	3.15	0.00	0.43	3.97	0.20	-0.02	0.07	0.02	0.27	1.71	5.95
Peru	0.98	2.09	0.04	0.71	3.82	-0.04	0.04	-0.11	0.00	-0.10	0.95	4.67
Uruguay	-0.31	1.34	0.00	-0.13	0.91	0.11	-0.01	-0.04	-0.01	0.05	1.53	2.49
Venezuela	1.35	1.26	0.01	0.56	3.18	0.00	0.00	-0.05	0.00	-0.05	-0.26	2.87

[a] Grand total for all-cause differences. Standard deviation for the differences in Table 1.

[b] Total for cause-specific differences.

Note: Values for Bolivia and Haiti correspond to the period 2000-2004.

Table A.3: Decomposition of differences in standard deviations and its components. Females, 2010-2014.

	Amenable diseases					External causes of death					Others	Total[a]
Country	Allocation	Spread	Timing	Joint	Total[b]	Allocation	Spread	Timing	Joint	Total[b]		
Argentina	-0.19	1.52	-0.01	-0.10	1.22	0.02	-0.06	-0.11	0.00	-0.15	0.89	1.95
Bolivia	-1.50	8.98	-0.01	-5.40	2.07	-0.86	0.20	-0.28	0.07	-0.87	10.31	11.50
Brazil	-0.06	2.02	0.09	-0.04	2.02	1.47	-0.01	-0.06	-0.09	1.32	1.01	4.35
Chile	-0.07	0.41	0.02	-0.01	0.35	0.32	-0.05	-0.11	-0.04	0.12	0.11	0.58
Colombia	0.20	2.10	0.33	0.18	2.80	2.51	-0.05	-0.01	-0.15	2.30	1.00	6.10
Costa Rica	0.09	0.86	0.05	0.03	1.03	0.50	-0.05	0.02	-0.01	0.46	0.35	1.84
Cuba	0.26	0.40	-0.01	0.03	0.68	0.15	0.00	-0.30	-0.04	-0.19	-0.02	0.47
Dominican Republic	0.38	3.26	0.06	0.47	4.17	1.52	-0.03	-0.16	-0.28	1.05	1.09	6.32
Ecuador	-0.17	2.88	0.09	-0.19	2.61	1.28	-0.02	-0.04	-0.08	1.13	1.90	5.64
El Salvador	-0.60	3.17	0.07	-0.73	1.91	3.19	-0.07	-0.11	-0.55	2.46	2.18	6.55
Guatemala	-0.22	4.16	0.06	-0.34	3.66	0.95	0.00	-0.21	-0.18	0.56	2.52	6.74
Haiti	-1.01	8.58	-0.04	-3.39	4.13	-0.02	0.06	-0.57	0.01	-0.52	7.04	10.65
Honduras	0.37	4.26	0.05	0.58	5.25	0.38	0.12	-0.47	-0.12	-0.10	1.81	6.97
Mexico	0.48	2.30	0.02	0.40	3.21	0.82	0.13	-0.28	-0.12	0.55	0.74	4.50
Nicaragua	0.65	2.84	0.06	0.69	4.25	0.66	-0.05	-0.06	-0.07	0.48	0.93	5.65
Panama	0.16	2.27	0.13	0.14	2.70	0.94	-0.03	0.17	0.12	1.20	1.45	5.35
Paraguay	0.00	3.51	-0.01	0.00	3.51	0.87	-0.04	-0.02	-0.05	0.75	1.75	6.01
Peru	0.49	2.82	0.07	0.50	3.88	0.00	-0.02	-0.26	0.00	-0.28	1.24	4.84
Uruguay	-0.41	0.93	0.01	-0.13	0.40	0.46	-0.03	-0.27	-0.11	0.05	1.03	1.48
Venezuela	0.57	1.22	0.20	0.29	2.28	1.34	-0.08	0.03	-0.06	1.23	0.69	4.20

[a] Grand total for all-cause differences. Standard deviation for the differences in Table 2.

[b] Total for cause-specific differences.

Note: Values for Bolivia and Haiti correspond to the period 2000-2004.

Table A.4: Decomposition of differences in standard deviations and its components. Males, 2010-2014.

Period	Country
2000-2014	Argentina, Brazil, Chile, Costa Rica, Ecuador, Mexico, Nicaragua, Panama, Paraguay and Uruguay
2000-2003	Bolivia
2000-2013	Colombia, El Salvador, Peru and Venezuela
2000-2012	Dominican Republic
2005-2014	Guatemala
2001-2004	Haiti
2008-2013	Honduras

Note: All benchmark countries have data available for years 2000-2014.

Table A.5: Availability of causes-of-death data on the World Health Organization mortality database for males and females.