# Compression of mortality: the evolution in the variability in the age of death in Latin America

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**Abstract**

Latin American countries are undergoing major changes in their mortality profiles due to unique epidemiological and health transitions in the region. The main goal of this paper is to study the evolution of the mortality age profiles and the distribution of age at death for a series of Latin America countries in order to identify the effects of mortality changes on the variability of age at death. We use data from different and alternative sources (WHO, LAHMD, and LAMBdA) to study this issue in the region. We first evaluate the quality of national-level mortality data overtime in Latin American countries. Using a relational model we estimate the mortality patterns by single year age-groups, for each country in Latin America. Lastly, we use traditional metrics of age at death variability to perform the analysis. Our results indicate that the quality of mortality data is improving over time for all countries we include. We also find a decrease in variability of age at death, and that the decrease has happened faster for females than for males. In recent years, increasing mortality due to external causes of deaths related to violence, have reduced the rise in life expectancy and birth and increased the variability in the age at death for several countries in the region. These results contribute to the study of mortality changes in Latin America looking at mortality compression and the variability of age at death. Over the last half-century there has been a reduction in the variability of age at death, but more recently, increases in external causes of death have been associated with a stagnation in the compression process. The analysis also provides some insight and questions about morbidity trends in the region.

Keywords: mortality, Latin America, compression, variability, data quality

## 1. Introduction

Mortality transition in developed countries, especially in Western Europe, has demonstrated the importance of economic development and improvements in living standards as main factors responsible for the historical decline of mortality within these populations (McKeown and Record, 1962; Preston, 1975; Cutler and Miller, 2005; Cutler, Deaton and Lleras-Muney, 2006). Improvements in nutrition and public health measures have at the same time, played an important role in this process (Fogel, 1986, Preston, 1975). Public health measures took a more prominent role in reducing mortality later on, with major improvements in sanitation (Cutler and Miller, 2005) and personal hygiene. Finally, in the mid-twentieth century, developments in medical interventions such as vaccinations and antibiotics to treat infectious diseases, became the most prevalent factor in reducing mortality (Cutler, Deaton and Lleras-Muney, 2006).

Because of the historical mortality decline in developed nations, a reduction in the variability of age at death has occurred (Wilmoth and Horiuchi, 1999), as part of a process related to what Fries (1980) calls the compression of mortality hypothesis. Fries (1980) states that survival curves become rectangular as mortality levels decline, i.e. deaths become concentrated in a narrow age interval, the slope of the survival curve in that range becomes steeper, and the curve itself begins to take a rectangular form, suggesting that human life expectancy is approaching its maximum potential value (Fries, 1980; Wilmoth, 1997; Wilmoth and Horiuchi, 1999).

Following Fries (1980), several authors examined empirical evidence related to mortality compression (Meyers and Manton, 1984a, 1984b; Go et al, 1995; Nusselder and Mackenbach, 1996; Wilmoth, 1997; Paccaud et al, 1998; Wilmoth and Horiuchi, 1999; Cheung et al; 2005; Edwards and Tuljapurkar, 2005; Cheung and Robine, 2007; Stallard, 2016). The focus of most studies is the relationship between the compression-rectangularization of the survival curve and the biological limits of the human lifespan. Wilmoth (1997) and Wilmoth and Horiuchi (1999) argue that the compression-rectangularization process is associated with reductions in the variability of age at death, as the distribution of age at death moves to the right, but the compression-rectangularization does not necessarily imply biological limits of the human lifespan (Wilmoth, 1997; Wilmoth and Horiuchi, 1999).

More recent developments suggest two processes of change in the distribution of age at death: 1) changes in variability, and 2) mortality shifting (Bongaarts and Feeney, 2003; Bongaarts, 2005; Canudas-Romo, 2008; Zureick, 2010; Bergeron-Boucher, 2015). Changes in variability is characterized primarily by a concentration of the distribution of deaths around the modal or mean age of death Shifting mortality means that the variability of age at death remains constant even as life expectancy continues to increase.

There are only a few studies on compression of mortality in developing countries, and those that do exist, focus on specific countries and periods of time (Gonzaga, Queiroz and Machado, 2009). There are not many comparative studies across countries in Latin America. This gap in the literature is closely related to the quality of mortality data present for most countries in the region. However, due to the peculiarities in health and mortality transition trajectories in the region (Frenk et al, 1991; Brevis et al, 1997; Araújo, 2012; Barreto, et.al, 2012; Mesle, Vallin and Garcia, 2016; Alvarez, Aburto and Canudas-Romo, 2018), analyzing changes in the sex and age-specific mortality patterns in Latin America adds important contributions to the literature and the debate about compression of mortality. In addition, it offers important hypotheses for mortality and population forecasts in the region. That motivated us to explore certain features of this process in the region and address the following research questions: Are Latin American and Caribbean (LAC) countries experiencing a reduction in the variability of age at death, along with a shift in the age of deaths to older ages? How have recent changes in the causes of death, particularly an increase in external causes of death, effected trends in the variability of age at death in LAC? In addition, how can these changes inform mortality forecasts? This paper therefore discusses old paradigms of mortality studies in LAC (data quality) countries as well as emerging paradigms (variability of age at death).

In LAC countries, the decline in mortality has not followed the same historical path observed in developed countries. In a short period over the last half century, most LAC countries have experienced major changes in health conditions influenced by demographic, socioeconomic and environmental processes, as a result of rapid industrialization and urbanization (Palloni, 1981 Palloni and Wyrick, 1981; Palloni, 1985; Palloni, Hill and Pinto-Aguirre, 1996; Palloni and Pinto-Aguirre, 2011; Mesle, Vallin and Garcia, 2016; Alvarez, Aburto and Canudas-Romo, 2018). In contrast to epidemiological and mortality transitions in developed countries, the peculiarities of LAC countries mortality trajectories, suggest less optimal projections for future longevity of the population (Palloni and Pinto-Aguirre, 2004;

2011, Palloni et al., 2005; Mesle, Vallin and Garcia, 2016; Alvarez, Aburto and Canudas-Romo, 2018) and little is known about the variation of age at death in the region.

## 2. Mortality developments in Latin America and Caribbean

The peculiarities in the general decline of mortality in LAC have been well documented by several studies (Palloni, 1981; 1985; Barreto, et.al, 2012; Mesle, Vallin and Garcia, 2016; Alvarez, Aburto and Canudas-Romo, 2018). Mortality transition in the region began between 1930 to 1940, while the same process in developed countries was already at a much more advanced stage (Palloni, 1981; 1985). Although the rapid transition of mortality is an intrinsic feature for LAC countries, there is significant heterogeneity in the process as some countries begin the transition earlier than others, as is the case in Argentina, Uruguay and Cuba (Guzman et al., 2006; Pantelides, 1996; Palloni, 1981; 1985). A widespread reduction in mortality in Latin America only began after 1950, significantly reducing the gap between developing and developed countries (Palloni 1981; Guzmán and Rodriguez, 1993).

Parallel to the decline in mortality, countries in the region have experienced epidemiological transition at different times and in the context heterogeneous health profiles (Frenk et al, 1990). In Brazil, for example, changes in mortality and morbidity patterns are responsible for the increases in life expectancy and reductions in the variability of age at death (Gonzaga, Queiroz and Machado, 2008; Borges, 2017, França et al., 2017). These changes follow a similar pattern to what has been observed in developed countries (Wilmoth and Horiuchi, 1999) and can be explained by an improvement in living conditions that first reduced the number of deaths caused by infectious diseases, and second, led to an increase in non-infectious diseases as the main cause of death, consequently changing the age profile of mortality (Schramm et al, 2004; Borges, 2017; França, et.al, 2017). At the same time, one can also observe an increase in mortality due to external causes – that is violence and vehicular and transit accidents - for most countries in the region (Nadanovsky et al., 2009; Waiselfisz, 2012; Aburto et al., 2016). It is unlikely that any of these countries are experiencing a transition path similar to that of more developed regions (Omran, 1971; 1982; Alvarez, Aburto and Canudas-Romo, 2018). Many LAC countries are characterized by overlapping stages of transition, with the resurgence of some diseases that were previously controlled, and a peculiar epidemiological polarization between countries and between different geographical areas and population sub-groups within a country.(Frenk et al., 1990; Schramm et al. 2004; Araújo, 2012, Borges, 2017;

Barreto, et.al, 2012; França et.al, 2017). The intrinsic health transition process identified in some countries in the region produces a scenario where the incidence of communicable diseases in adults and elderly adults is relatively high, compared to more developed regions (Frenk et al., 1990). Guatemala, for example, is considered to be in the pre-transitional stage, with a high proportion of deaths due to infectious diseases, while countries such as Mexico, Chile and Uruguay have reduced the incidence of infectious diseases and are in more advanced stages of health transition (Brevis et al, 1997; Palloni and Pinto, 2011). Among these three countries, Mexico is experiencing the longest transition, similar to that observed in Brazil (Chaimowicz, 1997), while Chile and Uruguay are considered to be closer to a post-transitional stage (Brevis et al, 1997).

The historical decline in mortality rates in developed countries has had two clear effects: the reduction in the variability of age at death and concentration of deaths at older ages (Nusselder and Mackenbach, 1996; Wilmoth and Horiuchi, 1999; Kannisto, 2000; Cheung et al, 2005; Edwards and Tuljapurkar, 2005; Stallard, 2016). Most of the reduction in the variability of age at death can be explained by the decline in mortality among younger age groups, especially infant and child mortality; and the concentration of deaths at older ages by structural changes and medical advances that reduce mortality from non-infectious diseases (Wilmoth and Horiuchi, 1999; Cheung et al, 2005). In fact, concentration of death at early and later ages have different implications for the variability of age at death (Engelman, Canudas-Romo and Agree, 2010; Engelman et al., 2014). However, in LAC countries it is not yet known whether the ongoing process of mortality decline will lead to the same situation.

In addition, a decline in mortality rates of the elderly population can be observed, leading to an increasingly older age at death (Campos and Rodrigues, 2004). Campos and Rodrigues (2004) also suggest that this phenomenon is still underway in Brazil and the region, and a further decline in the mortality rates at older ages can be expected in the coming years. If people are living longer, there are some important questions regarding the overall health conditions of the population. In more developed countries, there is a debate about the compression of morbidity hypothesis and alternative views on the association between mortality, morbidity and population health (Manton, 1982; Olshansky et al, 1991; Crimmins and Beltran-Sanchez, 2011). A decline in mortality rates, raises an important question about the distribution of disability and illnesses over the life cycle. Our study does not investigate

morbidity trends in the region, but our findings illustrate the dynamics of morbidity in the region over recent decades.

## 3. Data and Methods[1]

### 3.1 Mortality Data

In order to investigate the evolution of LAC countries' survival curves and the compression of mortality hypothesis, we used alternative datasets: Human Mortality Database (HMD)[2], Latin American Human Mortality Database (LAHMD, 2018)[3], Latin America Mortality Database (LAMBdA, 2018) and the World Health Organization (WHO) database[4]. We focused our analysis on three main points. First, using data from the Latin American Human Mortality Database and WHO we evaluated the quality of national-level mortality data overtime in LAC countries, using traditional demographic methods (death distribution methods) to estimate the level of completeness of death registries. Second, based on a model proposed by Himes, Preston and Condran (1994) we estimated an age pattern of mortality for LAC and for each country using a relational model to fit and extrapolate the mortality rates from 5 to 110 years old, by sex, for each country in the study over various time periods (staring year in parenthesis): Chile (1920), Mexico (1930), Brazil (1980), Argentina (1970), Colombia (1964), and Peru (1972), Costa Rica (1963), Puerto Rico (1970), Panama (1960), Guatemala (1964), Cuba (1970), Dominican Republic (1960), and Uruguay (1960). LAMBdA (2018) contains data for all countries from the starting year (given in parentheses above) until roughly 2010. WHO (2018) has data for all countries since 1970. We obtained mortality data from LAHMD (2018), from the starting year for Argentina, Brazil, Colombia, Ecuador, Peru and Mexico. Finally, we used well-known empirical measures (Wilmoth and Horiuchi, 1998) of the compression of mortality hypotheses to analyze the evolution of the distribution of deaths over age and time in order to identify the effects of changes in the variability of age at death.

In order to test the robustness of our estimates, we compared our results to survival curves available from the Latin American Mortality Database (LAMBdA, 2018)[5]. LAMBdA contains life tables adjusted for undercounting and for adult age misstatement by single year

[1] Codes and original data used in the analysis are available at: https://github.com/blanza/Compression
[2] www.mortality.org
[3] www.lamortalidad.org
[4] www.who.org
[5] http://www.ssc.wisc.edu/cdha/latinmortality/

age groups for 19 countries (LAMBdA, 2018). For some countries, life tables were available from the early 20th century. Life tables from LAMBdA use a variety of demographic and statistical methods to adjust death records for under registration (LAMBdA, 2015). Since the source for observed deaths per population, modeling and adjustment assumptions to correct and estimate death rates are different from our approach, we used survival curves from LAMBdA to compare the evolution of the variability of age at death in LAC countries.

We also used data from Sweden and selected countries in Eastern Europe (Bulgaria and Russia), from the Human Mortality Database. We included data for Eastern European countries to compare the evolution of mortality and trends in the variability of age at death in Latin America with countries that are also facing rapid changes in their mortality profile. Also, Russia and Bulgaria have experienced a different pattern of mortality reduction for males and females in recent years, which provides an interesting comparison to Latin America and Caribbean (Aburto and Van Raalte, 2018).

### 3.2. Death Distribution Methods

Limitations of mortality data in LAC are well-known, and include the under-counting of registered deaths (Palloni and Pinto-Aguirre, 2011). Thus, we first evaluated the quality of mortality data available overtime in Latin America. We evaluated the degree of death registry completeness. Several methods based upon equations of population dynamics have been developed to evaluate the coverage of reported deaths relative to the population. The death distribution methods (DDM) are commonly used to estimate adult mortality in a non-stable population (Timeaus, 1991). They compare the distribution of deaths by age with the age distribution of the living population and provide age patterns of mortality for a defined reference period. There are three main approaches: the General Growth Balance Methods (GGB) (Hill, 1987), the Synthetic Extinct Generation method (Benneth and Horiuchi, 1981), and the Adjusted Synthetic Extinct Generation method (Hill, You and Choi, 2009).

Bennett and Horiuchi's (1981) Synthetic Extinct Generations (SEG) method, uses age-specific growth rates to convert an observed distribution of deaths by age into the corresponding stationary population age distribution. Since in a stationary population, the deaths above each age x are equal to the population aged x, the deaths in the stationary population above age x provide an estimate of the population of age x. The completeness of death registration relative

to the population is estimated by the ratio of the death-based estimate of population aged x to the observed population aged x.

The GGB method is derived from the basic demographic balancing equation, which expresses the identity that the growth rate of the population is equal to the difference between its entry rate and exit rate. This identity holds for open-ended age segments x+, and in a closed population, where the only entries are through birthdays at age x. The entry rate x+ minus the growth rate x+ thus provides a residual estimate of the death rate x+. If the residual estimate can be calculated from population data from two population censuses and compared to a direct estimate using the recorded deaths, the completeness of death recording relative to population recording can be estimated (Hill, 1987; Hill, Choi and Timeaus, 2005; Hill, You and Choi, 2009). Hill, You and Choi (2009) proposed that the combination of SEG and GGB might be more robust than either one individually. The combined method consists of first applying GGB to estimate any changes in census coverage (k1/k2), using the estimate to adjust one of the censuses to make the two consistent, and then applying SEG using the adjusted population data in place of the original data.

The methods make several strong assumptions: that the population is closed to migration, that the completeness of recording of deaths is constant by age, that the completeness of recording of population is constant by age and that ages of the living and the dead are reported without error. We used the alternative proposed by Hill, You and Choi (2009) to evaluate the quality of mortality data in Latin America and estimate the level of completeness of death counts. Using the adjustment factor, we corrected the level of the mortality curve and used the adjusted curve to proceed with our analysis. We estimated completeness of death counts coverage using the R package DDM, available at https://CRAN.R-project.org/package=DDM.

### 3.3 Estimates of death rates and survival curves by single age

We used a relational model to estimate single age mortality using two steps. First, we estimated death rates per five-year age group, to deal with potential problems of age declaration for all Latin American countries. Then, we used a relational model (Himes, Preston and Condran, 1994; Palloni and Pinto-Aguirre, 2011) to fit and extrapolate the mortality rates from 5 to 110 years old for all countries, years and sex for all Latin American countries. This strategy allowed us to produce a linear relationship between a logit transformation of the observed death

rates and the logit of the standard model death rates. Then, the age pattern of mortality in the population under study can be expressed as the following linear function:

$$\Psi_{j,t}(x) = \alpha_{j,t} + \beta_{j,t}\Psi_s(x) \quad (1)$$

Where $\Psi_{j,t}(x)$ is a logit transformation of the death rate at age $x$ in population $j$ and year $t$; $\Psi_s(x)$ is a logit transformation of the death rate at age $x$ in the standard model and $\alpha_{j,t}, \beta_{j,t}$ are parameters to be estimated for each population and year.

In order to apply the relational model in Equation 1, we need a standard mortality age profile that can express the mortality pattern for all countries. Then, from the relational model, we use Equation 1 to estimate the mortality rates for each country and year (separately by sex).

We used a similar strategy as proposed by Himes, Preston and Condran (1994) to obtain a standard mortality age profile. Based on pooled data with observed adjusted mortality rates by country, year, sex and age (in five-year age groups from 5 to 85+ or 100+ depending on the data available for each country) we estimated the regression model (Equation 2) for each sex:

$$\Psi_{j,t}(x) = \delta + \sum \beta_x I_x + \sum \lambda_{j,t} CY_{j,t} \quad (2)$$

Where $\Psi_{j,t}(x)$ is a logit transformation of the estimated death rates in the country $j$ and year $t$; $I_x$ is a dummy variable for age $x$ (=1 if the death rates relates to age $x$, 0 otherwise). Since we have five-year age groups, we have used the middle of each five-year age interval from 7.5, 12.5, to 107.5. Then we have 20 age categories as dummy variables. $CY_j$ is a dummy variable for a combination between country $j$ and year $t$ (=1 if the death rates relates to country/year $j, t$ and 0 otherwise). Since we have 38 country/year combinations we have 37 categories for our dummy variable. Argentina/1920 were omitted as reference categories for country and year. $\delta, \beta_x, \lambda_{j,t}$ are appropriate parameters to be estimated.

From Equation 2, we obtained one $\beta$ coefficient for each age and one $\lambda$ coefficient for each country/year combination. In order to get a logit of the standard death rate at age $x$ from 7.5, 12.5,…., to 102.5 years old, we used the mean of the $\lambda$ coefficients to obtain a predicted value for the entire sample. Then, following Himes, Preston and Condran (1994), we used weighted least squares regression to fit and extrapolated the logit of the standard death rates

from age 5 to 110 (one-year age intervals). The weights are the number of observations (country/period combinations) available for each age.

The adjusted and extrapolated logit standard rates, by single ages, are used in the relational model in equation (1) to obtain smoothed logit death rates by sex and single ages for each country and year. Finally, to recover the age-specific death rates for each country/year we used the following equation (Equation 3):

$$\widehat{M}_{j;t}(x) = \frac{1}{\left(1+e^{\widehat{\Psi}_{j,t}(x)}\right)} \quad (3)$$

Where: $\widehat{\Psi}_{j,t}(x)$ is a smoothed logit death rate in the country $j$, year $t$ and age x and $\widehat{M}_{j;t}(x)$ is a smoothed death rate in the country $j$, year $t$ and age x.

### 3.4 Variability of Age at Death: alternative measures

We used two metrics for our analysis of compression of mortality. The first is the interquartile range (IQR). The IQR is based on the survival function ($l_x$) as the leading indicator of the variability of age at death (Wilmoth and Horiuchi, 1999). Together with measures of central tendency of age at death, the IQR has been used to evaluate the compression of mortality hypothesis (Fries, 1980). The IQR measures the concentration of deaths between first and third quartile around the median age at death, using the exact ages where the survival function equals 0.75 and 0.25, respectively. The age range between $l_x$ = 0.75 and $l_x$ = 0.25 represents the IQR. Van Raalte, and Caswell (2012) provide a detailed overview of different methods for calculating lifespan variation and their limitations.

The second measure of variability of age at death is the shortest age interval in which a given proportion of deaths are distributed in a life table, known as the C family. We focused on the C50, which is the age span corresponding to the most compressed 50 percent of deaths from the death distribution (Kannisto, 2000). Our choice for these two measures is based on its simplicity in terms of calculation and interpretation. Also, as suggested by Kannisto (2000), IQR and C50 give us an age interval in which half of all deaths take place, so it is of interest to compare the results from both measures. The medium and modal age at death are central indicators of length of life that can be evaluated together with IQR and C50, respectively. Details about the calculation of IQR and C50 using life table functions can be found in Wilmoth and Horiuchi (1999) and Kannisto (2000).

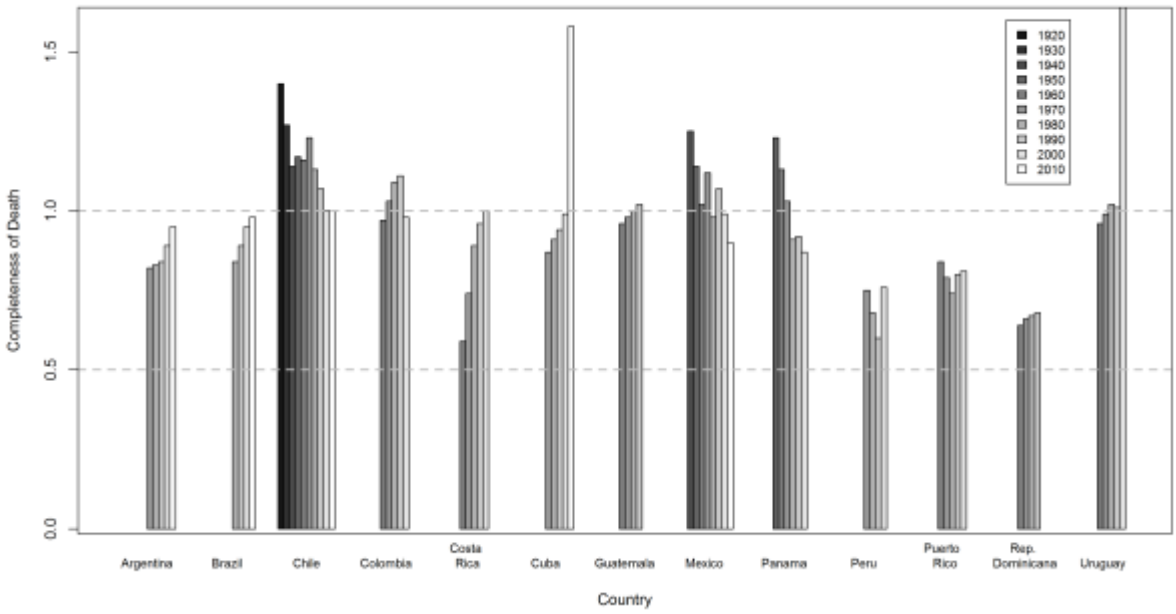
## 4. Results

### 4.1. Completeness of Death Counts Coverage

Figure 1 and Table A1 present the completeness of death counts for each country, period and sex in LAC countries. The quality of mortality data improved steadily over the last half–century as observed in other studies (Palloni and Pinto-Aguirre, 2011). In more recent years, intercensal years of 2000 to 2010, most of the countries in our analysis show near complete death count registration. For earlier decades, we observed through diagnostic plots, results not shown, that the points for both males and females at young ages are very irregular and lie off the fitted line leading to very unstable estimates of completeness. Also, the estimate of census coverage indicates better coverage in the first census compared to the second one, which is consistent with problems arising from low data quality, net emigration and errors in age declaration. Overall, the fit of the observations (death rates) improved over time and are relatively complete for the most recent periods. The estimates are more precise when fitting the models only for age groups 35 years and older.

However, we observed wide variation over time for different countries in Latin America. For example, Brazil has shown signs of improvement since 1980. In 1980, death counts registration in Brazil, was around 80% reaching almost 100% in 2010. Similar trends were observed in Costa Rica and Chile, where in more recent years the quality of death count registration is considered complete. In general, from 1990 (and for some countries since 1980) the results imply that age reporting is good, and that the assumptions required for our methods are met. It is important to note that for a large number of countries, estimates of completeness are above 100% for several years. This is related to the assumptions of the models and the overall data quality in those countries. Since we are more interested in analyzing the trends in age profile, we are less concerned with the correct estimate of the levels of mortality– since all the Death Distribution Methods adjust only the level of mortality and not the shape of the mortality age profile. The shape of the profile was adjusted when constructing the survival curves by single years of age.

**Figure 1- Completeness of Death Counts Coverage, Latin America, males, 1920-2010**




Source: Latin America Human Mortality Database (2018), Human Mortality Database (2018) and World Health Organization Database (2018)

### 4.2 Evolution of Survival Curves

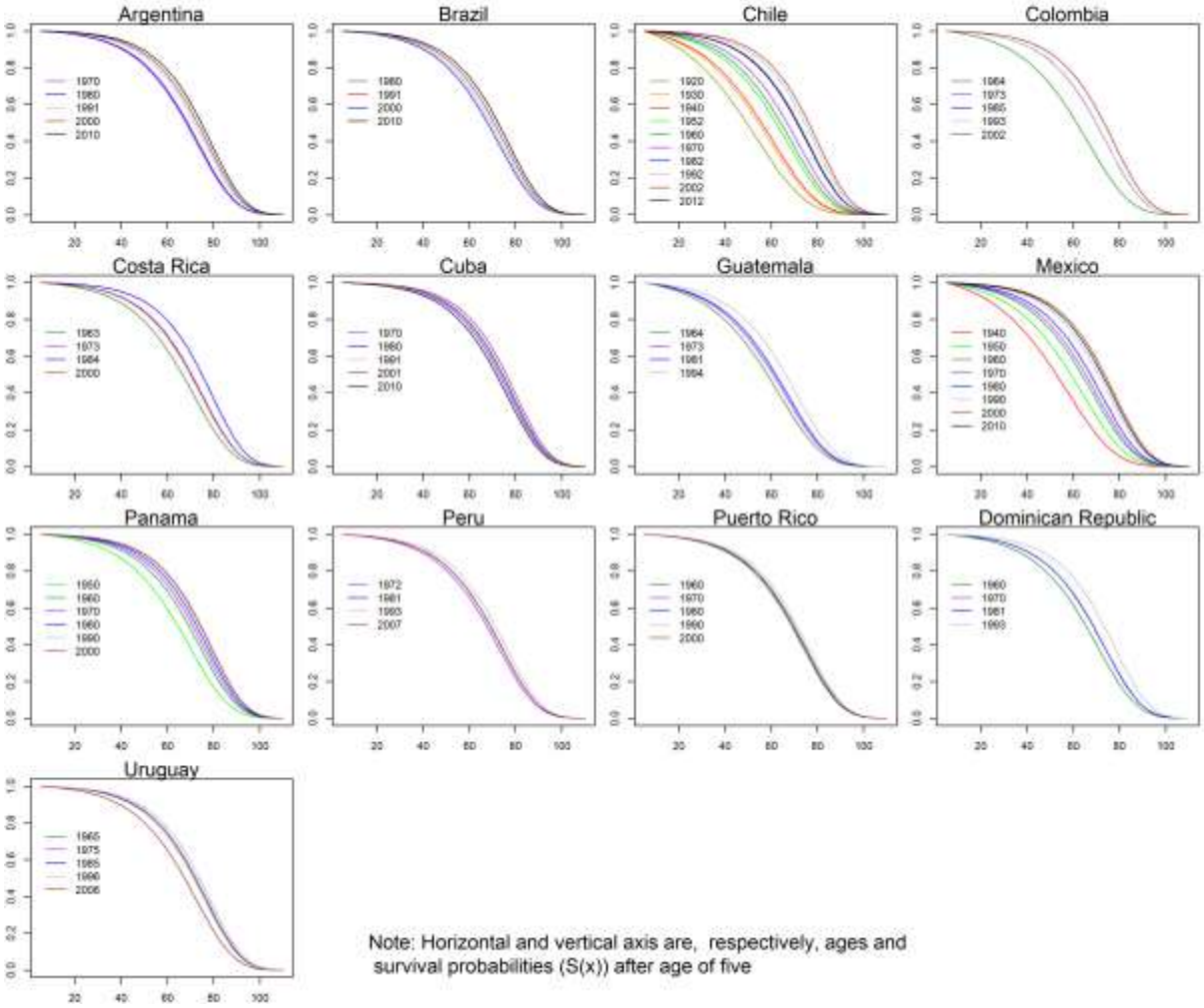
We began by visualizing the rectangularization process from the estimated survival curves. Figure 2 and Figure 3 show survival curves for males and females, respectively, for periods when data were available for each country. For most countries, the survival curves for males and females display the well-known property of rectangularization. In general, we observed that the survival function for each age is moving upward and the age of declining survivorship is increasing (moving to the right). For example, changes in the age profile are clearer for Chile and Mexico, which both have the longest series and demonstrate movement towards a more rectangular survival curve, such as observed in more developed countries. Since the curves do not show age groups below 5 years of age, one cannot observe the fast decline in infant and child mortality (You, et.al 2015). Edwards and Tuljapurkar (2005) argue that the rectangularization process should not be investigated from 0 years of age, but rather they suggest beginning at 10 years of age for more developed countries since this is the age with the

lowest mortality levels. We opted to show our results from 5 years of age to avoid possible impacts of very high infant and child mortality in the region.

The changes in mortality levels in Latin America imply that a rapid change in life expectancy has occurred in the last half century. On average, the countries in the region experienced improvements in life expectancy by more than one year per decade. For instance, Mexico and Chile had faster increases in life expectancy at birth gaining around 4 years per decade in the last half century (CELADE, 2004; Albala et al., 2011). Brazil has seen an increase of about 3.5 years since the 1950s, but has slowed down in the last twenty years with improvements closer to 2.0 years per decade between 1990 and 2010 (IBGE, 1981, 2013). Similarly for all countries and sexes, the rate at which life expectancy has increased in the past few decades has decreased, compared to earlier periods of improvement.

The results show an important pattern for males in almost all countries over the last few decades. We observed a stagnation or even reversal on the increasing trend of survival probabilities and rectangularization. The main explanation for these reversals is the increase in mortality by external causes in most LAC countries in the last few decades (Alvarez, Aburto and Canudas-Romo, 2018). There is much evidence to support our observations of stagnation or reversal in the increase of life expectancy in some LAC countries in the last few decades (Nadanovsky et al., 2009, Canudas-Romo and García-Guerrero, 2013; Aburto et al., 2016). According to Aburto et al. (2016), the increase in homicides after 2005 in Mexico could be the main cause of the reversal of life expectancy increases among males and a reduction in the gains observed for females .. The increased mortality due to external causes of death affects young adults, mainly males, having a direct impact on the variability of age at death (Aburto and Van Raalte, 2018; Borges, 2017; Alvarez, Aburto and Canudas-Romo, 2018).

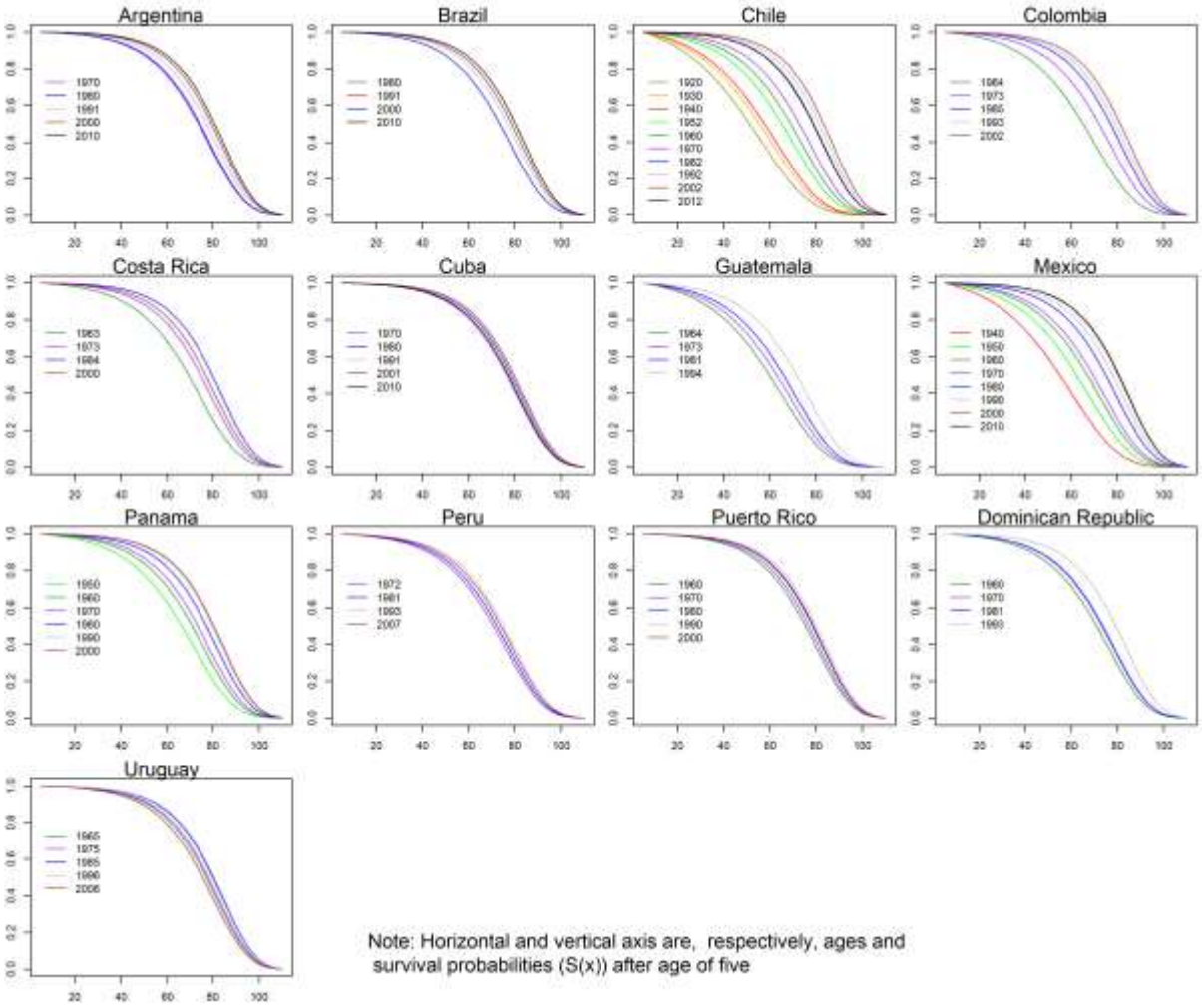
**Figure 2- Estimated males survival curves (Sx), Latin American Countries, (1920-2010)**




Source: Latin America Human Mortality Database (2018), Human Mortality Database (2018) and World Health Organization Database (2018)

It is important to consider that some of the trends observed could be related to the assumptions imposed by the methods used to estimate the undercount of death counts registration completeness . The recent demographic dynamics in most LAC countries could lead to unreasonable coverage estimates by those methods. For example, in Brazil, according to Queiroz et al (2017), DDM estimates for some subnational regions showed a decrease or even an over reporting in death coverage in the last decades, a situation that is not reasonable since the quality of records in Brazil has improved since 1980 (Paes, 2005; de Mello Jorge et al., 2007; Queiroz et al., 2017).

**Figure 3- Estimated females survival curves (Sx), Latin American Countries, (1920-2010)**




Source: Latin America Human Mortality Database (2018), Human Mortality Database (20184) and World Health Organization Database (2018)

### 4.3. Variability of age at death

We followed the procedure proposed by Wilmoth and Horiuchi (1999) and Kannisto (2000) and calculated the interquartile range (IQR) and the shortest age interval in which 50% of deaths take place (C50), to analyze tendencies in the variability of age at death in LAC countries. We show the results in Figure 4 and Figure 5. The top panel in each figure shows the IQR and C50, respectively, for males and females for all LAC countries selected in this study, based on data from LAHMD and UN databases. To compare and test our estimates, we also show on the bottom panel the IQR estimates based on LAMBdA. Despite the differences within the period of available data, we observed similar paths for longevity based on different sources

of data until the 1990s or 2000s. Results based on the LAMBdA database do not show a reversal in most LA countries in recent years. However, it is clear there is a deceleration on the decline of IQR based on both datasets. We argue that the differences in original data and methods can explain these results. First, estimates from LAMBdA include a greater number of countries than LAHMD. Even if estimates from both data sources are based on the same relational model[6], one may observe different parameter estimates due to different modeling strategies. Second, different Death Distribution Methods (DDM) could be used to estimate completeness of deaths. In this study we used a combination of different DDM and the evaluation of their performance was based on a graphic inspection.

The top panel in Figure 4 also shows results for Sweden (1920-2010), Bulgaria (1950-2010) and Russia (1959-2010). Sweden has experienced a historical mortality transition and has been used as a benchmark to explain the compression of mortality hypothesis (Wilmoth and Horiuchi, 1999). We selected Bulgaria and Russia for comparison because they have shown increases in mortality rates due to external causes over the last half-century, especially after 1989.

In the early 1920s, for both sexes, the IQR in Sweden was higher than Chile, the only LAC country with available data in the early 1900s. This higher variability in age at death could be explained by high incidence of young adult mortality due to tuberculosis and other infectious diseases (Horiuchi, 1999). It is also possible that since infant and child mortality in Chile around 1920, were so much higher than in Sweden, those who survived the first few years of life died later on in a more concentrated age range. However, deaths in Sweden were more distributed across the age range in the same period of time, especially for young adults. In Chile, significant declines in IQR started 20 years after Sweden for both sexes. However, the levels of IQR and C50 in Sweden fell very rapidly during the following decades.

We observed greater differences between IQR (Figure 4) and C50 (Figure 6) in high mortality populations, as occurred in LAC during the second half of the last century. Usually, for the same country, C50 shows a smaller dispersion than IQR, a result that makes C50 more useful than IQR in locating the greatest concentration of deaths around a central indicator of length of life (Kannisto, 2000). Since IQR measures variability on a percentile scale, its value

[6] Estimation of mortality rates in LAMBdA, as described by Palloni and Pinto-Aguirre (2011), are still based on the relational model proposed by Himes, Preston and Condran (1994).

is affected by high mortality in younger ages, a situation frequently observed in populations going through mortality transition. However, as argued by Kannisto (2000), differences can be narrowed down as mortality continues to decline overtime.

For some countries, we observed a convergence trend in the variability of age at death, especially for females. In Mexico, we saw significant changes in the variability of age at death, with a path like Chile's after 1940. The variability of age of death in Mexico, as measured both by IQR and C50, decreased by almost 8 years for females and more than 5 years for males, representing a significant reduction in variability over the 70 years studied.

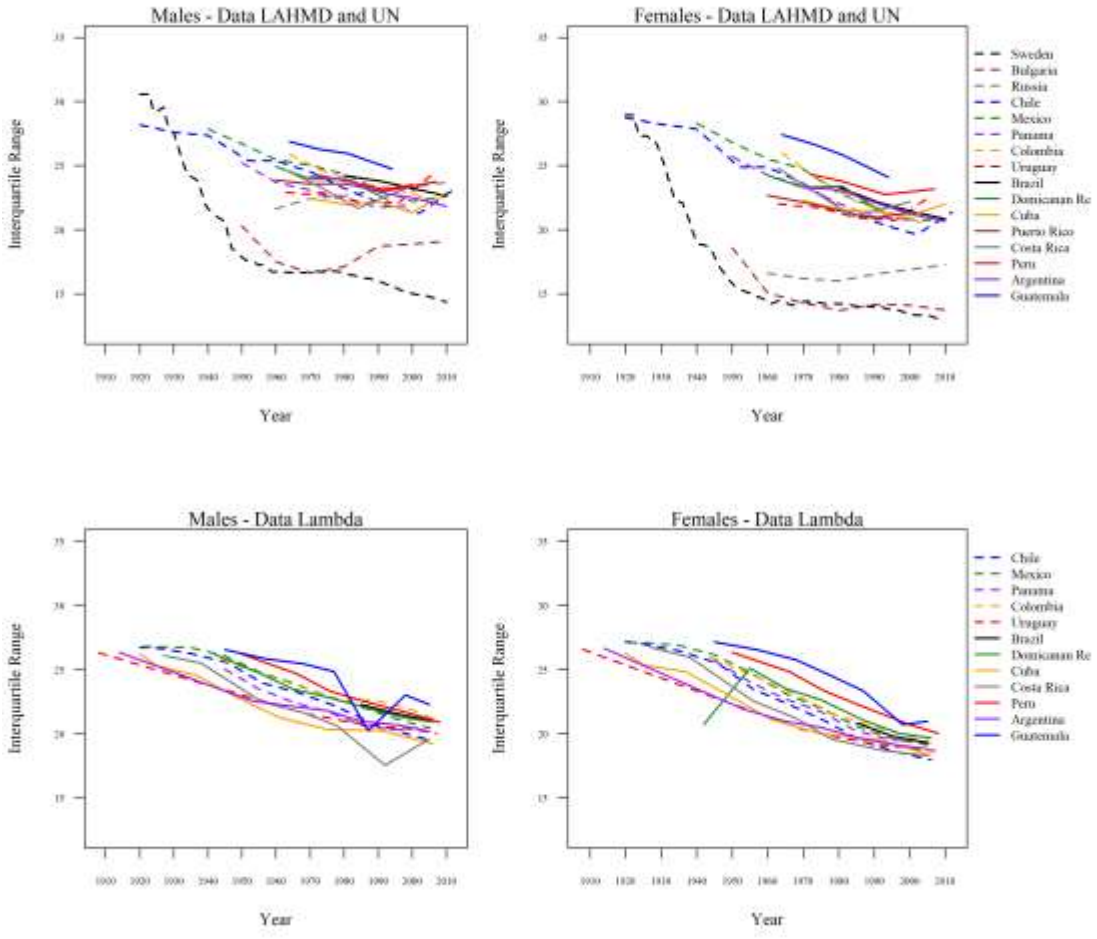
It is interesting to note that most countries (including Chile and Mexico) observed a declined followed by a period of stability, or even a small increase, in IQR and C50 after 1990s or 2000s. These remarkable reversals in LAC countries' variability of age at death over the last couple decades, can perhaps be attributed to the increase in external causes of death occurring in most LAC countries, especially amongst males (Nadanovsky et al., 2009, Aburto et al., 2016, Alvarez, Aburto and Canudas-Romo, 2018), which is preventing further mortality compression.

In addition, there are several features distinguishing the pattern of aging in the region, compared to more developed countries (Palloni and Pinto-Aguirre, 2004; 2011; Palloni et al, 2007; 2011). Due to different epidemiological cohorts, it is very difficult to predict the future health and mortality profile of the older populations in LAC countries (Palloni et al, 2007). The peculiarities of the mortality transition in LAC countries suggests a deceleration on longevity and points out a less optimistic scenario in the future health conditions for older populations (Palloni and Pinto-Aguirre, 2004; 2011). The stagnation or even increase in premature deaths after 1990s or 2000s, due to homicide, violence and transit accidents (Palloni and Pinto-Aguirre, 2011; França, et.al, 2017; Borges, 2017; Alvarez, Aburto and Canudas-Romo, 2018), are likely responsible for the deceleration of compression of mortality in the region.

Despite the different levels of variability measures, we observed very similar paths of the variability of age at death between countries in the region and Russia and Bulgaria over the last couple decades, especially for males. A decline followed by an increase in variability of age at death is observed for those countries based on both measures (IQR and C50). While in Latin America the increase in the variability of age at death is related to an increase in violence and transit accidents, the main causes of death in Bulgaria and Russia are related to alcohol consumption and premature deaths attributed to accidents, suicide and violence (Mckee and Shkolnikov, 2011; Zaridze et al, 2014; Bobak et al, 2016).

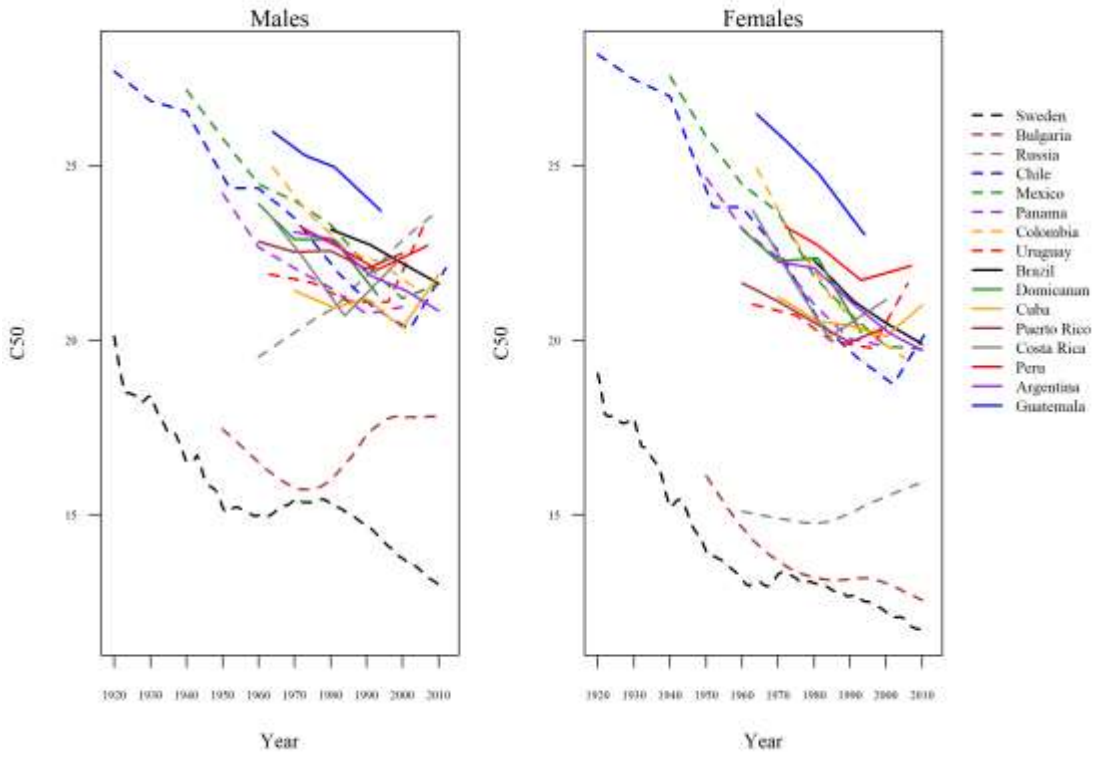
The reversal of variability of age at death trends in the last few decades is not only observed for Brazil, Argentina and Colombia, but for other countries in the region as well. However, reductions in IQR and C50 in those countries seem to have decelerated in the last few years. This is an important area of study and it is relevant to investigate trends in causes of deaths across regions and ages to better understand the results. In the case of Brazil, we hypothesize that the rapid decline in infant mortality in the last few decades may compensate for the rise in adult mortality and affect the reversal on variability of age at death.

**Figure 4: Evolution in Interquartile Range (IQR), Latin America, 1920-2010**




Source: Latin America Human Mortality Database (2018), Human Mortality Database(2018), World Health Organization (20184) and Latin American Mortality Database (LAMBdA, 20185).

**Figure 5: Evolutions in the "shortest age interval in which a 50% of deaths take place" (C50), Latin America, females, 1920-2010**



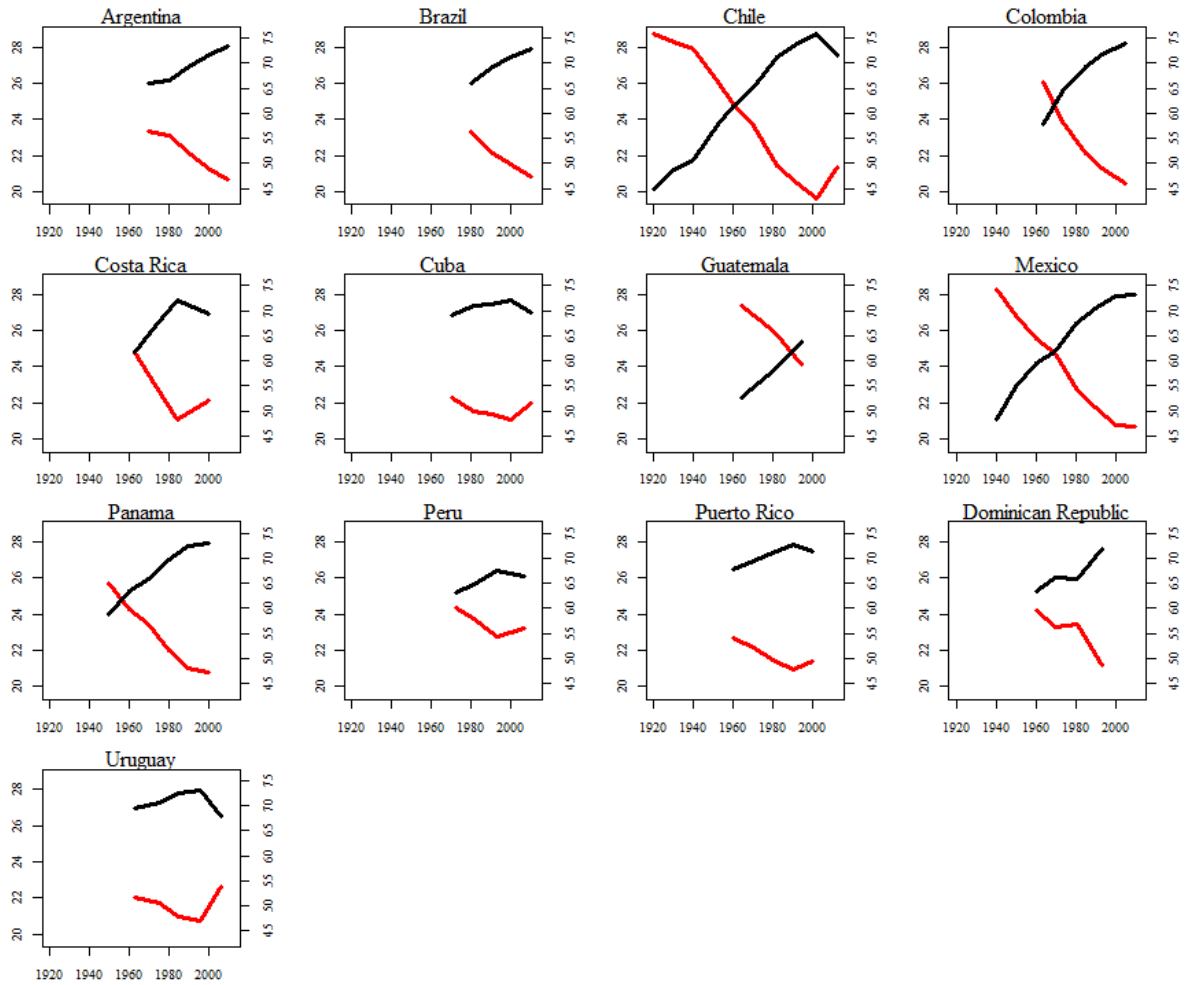

Source: Latin America Human Mortality Database (2018), Human Mortality Database(2018) and World Health Organization (2018).

Figure 6 and Figure 7 show the evolution of life expectancy at age 5 against IQR, for females and males, respectively. We find that for all countries in the study, as life expectancy at age 5 increases, there is a decline in the variability of the age at death. The inverse relationship between variability of age at death and life expectancy is also clear, since increases, decreases or stagnation in life expectancy trends are associated with similar changes in IQR.

This finding holds with Canudas-Romo's (2008) conclusion, which states that the increasing modal age at death illustrates changes from a dominance of child mortality reductions to a dominance of adult mortality reductions. This process has been described as a shifting mortality process where the bulk of deaths around the modal age at death move toward older ages. This process has likely taken place in many countries in the region over the last fifty years. Latin America has experienced increases in life expectancy at birth over the last few decades (Palloni and Pinto-Aguirre, 2011) while the variability of age at death has stagnated or even increased, as we have shown by looking at the trends in IQR and C50.

Based on the results, we identify four different groups of countries according to sex and path on life expectancy at 5 years of age - e(5) - and IQR. For males, only Argentina and Brazil showed increases in e(5) with a reduction in the variability of age at death. Mexico, Puerto Rico and Uruguay are interesting cases, as they show a stagnation in the evolution of life expectancy at age 5 and in the measure of compression of mortality. The stagnation of the decrease in variability of age at death for Males in Colombia in the 1980s and 1990s (Palloni and Pinto-Aguirre, 2011) demonstrates the impact of increasing mortality due to external causes of deaths in the country. We observed a similar trend for females in Colombia, Guatemala and Panama. For other countries, we observed a reversal or stagnation for both indicators over the last period. Overall, we observed trends for each country that are closely related to their stage of demographic and epidemiological transition. For instance, Peru and Guatemala still present high levels of child mortality, compared to other Latin American and Caribbean countries, like Chile and Costa Rica (Guzman et al., 2006).

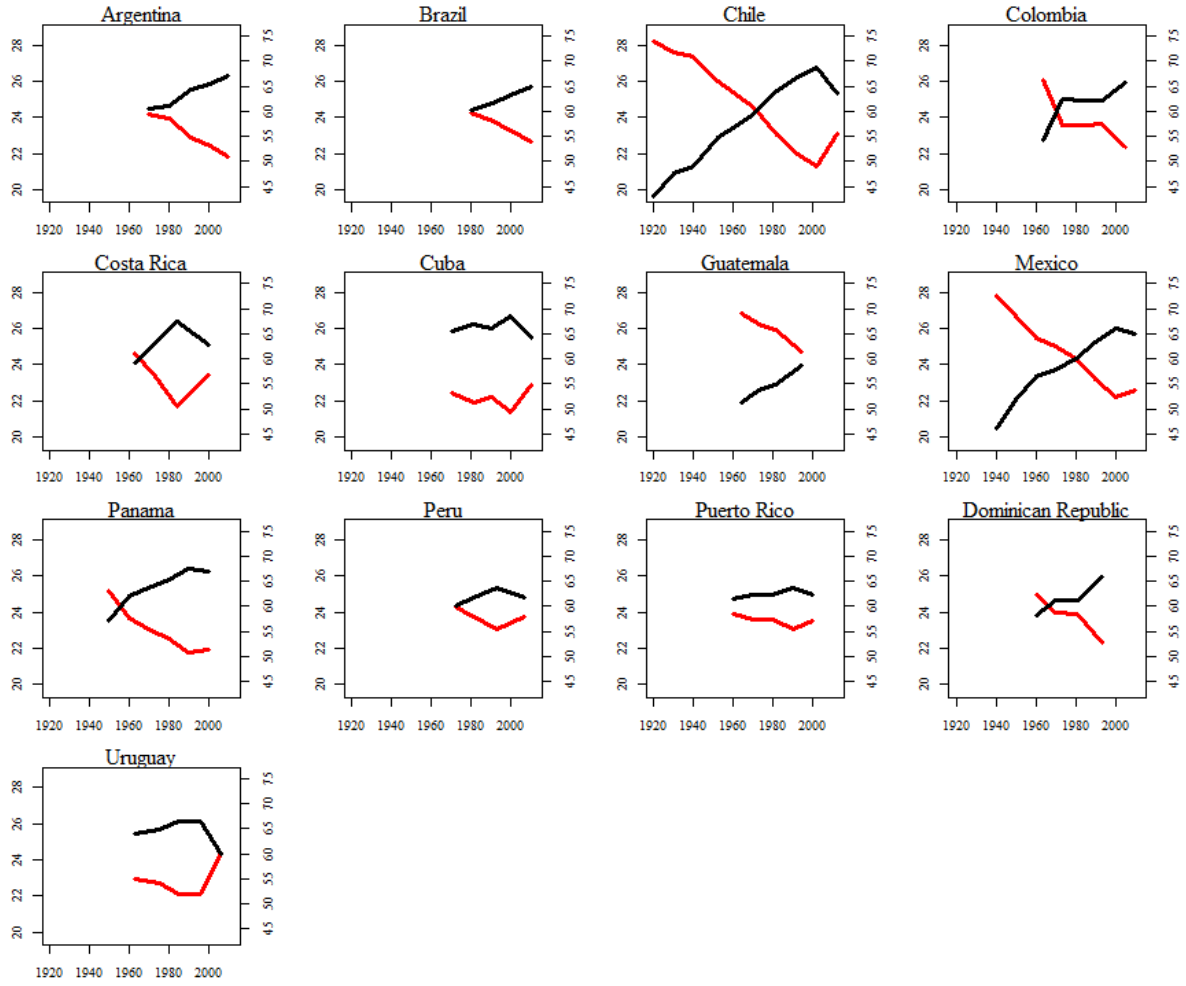
**Figure 6: Interquartile range and life expectancy at age 5, Latin America, 1920-2010, females**




Source: Latin America Human Mortality Database (2018), Human Mortality Database (2018) and World Health Organization Database (2018)

Note: Right and left vertical axis are IQR and Life Expectancy at age 5 - e(5), respectively. Horizontal axis are years for available data. Solid red and black lines are IQR and e(5), respectively.

**Figure 7: Interquartile range and life expectancy at age 5, Latin America, 1920-2010, males**




Source: Latin America Human Mortality Database (2018), Human Mortality Database (2018) and World Health Organization Database (2018)
Note: Right and left vertical axis are IQR and Life Expectancy at age 5 - e(5), respectively. Horizontal axis are years for available data. Solid red and black lines are IQR and e(5), respectively.

## 5. Conclusion

The main result of this paper shows that overall males and females in the LAC region have lower life expectancy compared to more developed economies, and face greater variability in the age at death. The first important analysis we present is the evaluation of the quality of information on deaths available for a series of LAC countries over the past half-century. We contributed to the analysis of data quality, following Palloni and Pinto-Aguirre (2011), by producing estimates for males and females separately. Our results indicate that the quality of

mortality data is improving over time for all countries included in this study, and can be considered high quality, making it a very useful tool for studies of mortality in Latin America.

We also examined the changes in the mortality pattern of the population in each country over the past few decades, to identify changes in the variability of age at death. For LAC countries who have historically experienced low-mortality rates, we observed that a reduction in the variability of age at death is currently underway. However, there is one additional important finding. The stagnation or reversal in recent decades, accompanied by continued increases in life expectancy at birth (Palloni and Pinto-Aguirre, 2011; Alvarez, Aburto and Canudas-Romo, 2018) indicates that the distribution of deaths is shifting to older ages. In conclusion, despite of significant reduction of infant and child mortality (Palloni and Pinto-Aguirre, 2011; Alvarez, Aburto and Canudas-Romo, 2018) the increase or stagnation of premature deaths, due to violence and transit accidents, is responsible for the deceleration the compression of mortality in LAC countries (Barreto, et.al, 2012; Davila-Cervantes and Agudelo-Botero, 2018)

The analysis by sex indicates that the reduction in variability of age at death has been greater for females, than for males. The difference in variability of age at death corroborates historical analyses performed in developing countries of mortality differentials by sex (Barrreto, et.al, 2012; Palloni and Pinto-Aguirre, 2011). This may be associated with a lower risk exposure, especially for external causes of deaths (homicides and accidents) or a lower socio-economic heterogeneity among women. In general, we find that for most countries in the region there, external causes of death negatively contribute to the evolution of life expectancy and reduction in the variability of age at death (Alvarez, Aburto and Canudas-Romo, 2018).

Our findings about sex differentials and trends in the variability of age at death are very important in supporting hypotheses on forecasting sex and age-specific mortality rates. The deceleration, stagnation or even reversal of IQR trends, means that considering only the past changes in the age mortality rate profiles, as stochastic methods do, is not be enough to explain future changes. Demographers must be able to inform forecasting models of any evidence around the compression of mortality hypothesis.

The study of compression of mortality and variability of age at death are very important and contribute to a better understanding of the changing health status of the elderly population, especially regarding the duration of active and disabled years of life around the age of death (Stallard, 2016; Edwards and Tuljapurkar, 2005). In fact, a reduction in the variability of age at

death with an increase in the average age of death is of crucial importance for public health planners, since the diseases that affect these individuals are chronic, mostly requiring monitoring of conditions over a long period of time (Stallard, 2016). As noted by Canudas-Romo (2010), delayed mortality implies that a more heterogeneous group of the population is reaching older ages and we can expect that health differentials and disparities that are common in early life in LAC, are now persisting in older age groups. In the near future, health systems in Latin America, and families, will have to deal with a larger and more diverse range of health issues, at older ages. This might imply larger costs and more complex interventions to mitigate the differences.

Another important aspect to highlight, according to Paccaud et al. (1998), is that given the heterogeneity of mortality among populations, the main issue to investigate is the variation around the age at death and not the central age of death. In this regard, the compression process should also be a related improvement in the state of health amongst the elderly. One can argue that the reduction in disability levels, occurs around the age of death (Paccaud et al, 1998). That is, it would be a process whose origin would, in fact, be the compression of morbidity (Fries, 1980, 1984). In other words, since the health status of the elderly is improving, there is a corresponding increase in years of life free of disability (Cambois , Robine and Hayward , 2001; Baptista , 2003; Camargo , Rodrigues and Machado , 2003; Romero Milk and Szwarcwald , 2005), thereby leading to overall improvements in health conditions at older ages.

The concept of compression of morbidity, as originally proposed by Fries (1980), is based on two assumptions: an upper limit to human longevity, and delay in age at onset of chronic conditions. Under these assumptions, a trend of significant decline in mortality rates, with the existence of a biological limit to human longevity (Bongaarts and Feeney, 2002), could trigger a process of compression of mortality or rectangularization of the survival curve at older ages (Fries, 1980 ; Wilmoth, 1997; Wilmoth and Horiuchi, 1999). Thus, the original concept of the compression of morbidity, under the assumption of a fixed limit to human longevity, would mean an increase in the average number of years free of disabilities (Fries, 1980; Nusselder, 2003). In this sense, the compression of morbidity would be related to an increase in the average age of the onset of chronic conditions in the elderly, leading to people living longer in better health (Nusselder , 2003).

An important limitation of the study is related to the data sources used to produce the estimates of survival curves. In addition to the under-registration of death counts in most of the

vital registration systems in Latin America, we might find problems with errors in the age declaration of age, which may occur within the data source for deaths and population. The tendency to over-state age is lower in death records compared to live populations. In this case, considering that errors in age declaration is higher in the census than in the death registry, especially at older ages, where the errors are larger, an over-statement of ages in the census may underestimate the specific mortality rates and resulting in a lower number of estimated deaths at these ages. If it is more common in the census is to declare an age lower than the true, then the number of deaths at older ages could be over-estimated, leading to the false impression of a higher concentration of deaths at advanced ages. However, if it is reasonable to assume that the standard errors of the old age statement has been roughly constant over time, the results would not be compromised, because the changes in the variability of age at death are related to changes in the structure of mortality, not their level. An additional limitation refers to the use of period data to estimate compression of mortality in a period of declining mortality. The trends would be better observed if we had available cohort mortality data. But, as noted by others, our results provide, at least, a conservative measure of the compression of mortality in Latin America.

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Table A.1 – Countries, Periods Covered and Estimates of Completeness of Death Counts, Latin America, Males and Females

| Country | Intercensus period | Males | Females |
|---|---|---|---|
| Argentina | 1960-1970 | 1.99 | 2.20 |
| Argentina | 1970-1980 | 0.77 | 0.46 |

| | | | |
|---|---|---|---|
| **Argentina** | 1980-1991 | 1.03 | 1.14 |
| **Argentina** | 1991-2000 | 1.00 | 1.00 |
| **Argentina** | 2000-2010 | 1.00 | 1.00 |
| **Brasil** | 1980-1991 | 0.84 | 0.76 |
| **Brasil** | 1991-2000 | 0.95 | 0.90 |
| **Brasil** | 2000-2010 | 0.98 | 0.96 |
| **Chile** | 1920-1930 | 1.15 | 1.22 |
| **Chile** | 1930-1940 | 1.15 | 1.23 |
| **Chile** | 1940-1952 | 1.14 | 1.39 |
| **Chile** | 1952-1960 | 1.16 | 1.23 |
| **Chile** | 1960-1970 | 1.23 | 1.26 |
| **Chile** | 1970-1982 | 1.13 | 1.14 |
| **Chile** | 1982-1992 | 1.07 | 1.07 |
| **Chile** | 1992-2002 | 1.00 | 1.00 |
| **Chile** | 2002-2012 | 1.00 | 1.00 |
| **Colombia** | 1951-1964 | 1.35 | 1.74 |
| **Colombia** | 1964-1973 | 0.98 | 1.02 |
| **Colombia** | 1973-1985 | 1.09 | 1.14 |
| **Colombia** | 1985-1993 | 1.11 | 1.03 |
| **Colombia** | 1993-2005 | 0.98 | 1.12 |
| **Costa Rica** | 1951-1963 | 0.70 | 0.56 |
| **Costa Rica** | 1963-1973 | 0.87 | 0.87 |
| **Costa Rica** | 1973-1984 | 0.89 | 0.83 |
| **Costa Rica** | 1984-2000 | 1.02 | 1.16 |
| **Cuba** | 1953-1970 | 1.34 | 1.41 |
| **Cuba** | 1970-1981 | 1.05 | 1.01 |
| **Cuba** | 1981-1993 | 0.98 | 0.98 |
| **Cuba** | 1993-2002 | 1.00 | 1.00 |
| **Dominican Republic** | 1950-1960 | 0.81 | 1.19 |
| **Dominican Republic** | 1960-1970 | 0.67 | 0.86 |
| **Dominican Republic** | 1970-1981 | 1.07 | 1.23 |
| **Dominican Republic** | 1981-1993 | 1.22 | 0.87 |
| **Guatemala** | 1950-1964 | 1.38 | 1.49 |
| **Guatemala** | 1964-1973 | 1.10 | 1.11 |
| **Guatemala** | 1973-1981 | 1.30 | 1.31 |

| | | | |
|---|---|---|---|
| **Guatemala** | 1981-1994 | 1.31 | 1.33 |
| **Mexico** | 1930-1940 | 1.10 | 1.26 |
| **Mexico** | 1940-1950 | 1.35 | 1.51 |
| **Mexico** | 1950-1960 | 1.20 | 1.28 |
| **Mexico** | 1960-1970 | 1.13 | 1.37 |
| **Mexico** | 1970-1980 | 1.10 | 1.19 |
| **Mexico** | 1980-1990 | 1.11 | 1.15 |
| **Mexico** | 1990-2000 | 1.00 | 0.98 |
| **Mexico** | 2000-2010 | 1.00 | 1.00 |
| **Panama** | 1950-1960 | 1.23 | 1.00 |
| **Panama** | 1960-1970 | 1.03 | 1.07 |
| **Panama** | 1970-1980 | 0.91 | 0.99 |
| **Panama** | 1980-1990 | 0.92 | 0.89 |
| **Panama** | 1990-2000 | 0.87 | 0.87 |
| **Panama** | 2000-2010 | 1.00 | 1.00 |
| **Peru** | 1961-1972 | 1.05 | 1.10 |
| **Peru** | 1972-1981 | 0.83 | 0.78 |
| **Peru** | 1981-1993 | 0.72 | 0.73 |
| **Peru** | 1993-2005 | 0.77 | 0.81 |
| **Puerto Rico** | 1960-1970 | 1.39 | 1.72 |
| **Puerto Rico** | 1970-1980 | 1.99 | 1.23 |
| **Puerto Rico** | 1980-1990 | 1.28 | 1.20 |
| **Puerto Rico** | 1990-2000 | 1.16 | 1.05 |
| **Puerto Rico** | 2000-2010 | 1.00 | 1.00 |
| **Uruguay** | 1963-1975 | 0.96 | 0.96 |
| **Uruguay** | 1975-1985 | 0.99 | 0.945 |
| **Uruguay** | 1986-1996 | 1.020 | 0.93 |
| **Uruguay** | 1996-2006 | 1.010 | 0.96 |

Source: Latin America Human Mortality Database (2018), Human Mortality Database (2018) and World Health Organization Database (2018)