Regional Disparities in Brazilian Adult Mortality: an analysis using Modal Age at Death (M) and Compression of Mortality (IQR)

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Abstract

This paper examines mortality differentials in Brazil and states between 1980 and 2010, using the Brazilian Ministry of Health Database. We use Modal age at death and measures of mortality compression to analyze regional and gender differences. We estimate age-specific mortality rates by single ages using two approaches: Wilmoth and colleagues (2012) Log-Quad approaches and Topal's method proposed by Gonzaga and Schmertmann (2016). Our results show that provincial disparities in mortality in general across regions of the country. Moreover, based on the modal age at death and the interquartile range (IQR) of ages at death. We find that there is a process of compression of mortality with increasing modal age at death.

Keywords: Brazil, Modal age, mortality levels, regional differences

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Introduction

Life expectancy has been rising for, at least, the last 160 years (OEPPEN & VAUPEL, 2002). Although there is an important debate about the biological limits of longevity, there is no evidence that human lifespan reached a limit (OEPPEN & VAUPEL, 2002; CANUDAS-ROMO, 2008; OUELLETTE & BOURBEAU, 2011). In more developed countries, mortality reduction, since the 1960, is concentrated in older ages (HORIUCHI et al., 2013; OEPPEN & VAUPEL, 2002). After the compression of mortality process, the shifting of the mortality curve may best represent the pattern of mortality change in those countries (WILMOTH & HORIUCHI, 1999; CHEUNG & ROBINE, 2007; CANUDAS-ROMO & WILMOTH, 2007; CANUDAS-ROMO, 2008). In the developing context, however, we know little about those processes (GONZAGA & COSTA, 2016; GONZAGA et al. 2017; WILMOTH et al., 2012).

In recent years, a large body of literature used the modal age at death (M) to analyze mortality changes in low mortality countries (KANNISTO, 2000; KANNISTO, 2001; CHEUNG & ROBINE, 2007; CANUDAS-ROMO, 2008, 2010; BERGERON-BOUCHER et al., 2015). The modal age at death is more sensitive to the mortality change at higher ages and is as a good tool to explain the current pattern of mortality variation in such countries (HORIUCHI et al., 2013). The associated processes of compression of mortality and the rectangularization of survival curve have been used to explain how mortality changed. The first process refers to the concentration of the deaths in a smaller age interval. While in the second, the survival curve becomes more rectangular as the probability of surviving to higher ages increases (OUELLETTE et al., 2012, WILMOTH & HORIUCHI, 1999). More recently, in low mortality countries, the compression of mortality stopped and the shifting of the mortality curve are observed. In that process, modal age of death rises while the variability above the mode remains stable (CANUDAS-ROMO, 2008; CHEUNG et al. 2009; CHEUNG & ROBINE, 2007).

In developing countries, there are few studies using modal age at death or the compression of mortality. Part of the challenges posted to analyze the evolution of mortality indicators in such countries is related to the poor data quality (HILL, 2017; WILMOTH et al., 2012), especially in countries with great regional heterogeneity in socioeconomic and demographic indicators. In recent decades, most countries in Latin America, and especially in Brazil, experienced an accelerated decline in infant, child

and adult mortality. The average gain in life expectancy at birth between 1950 and 2010 was about 15 years, a much faster process than what happened in developed countries. In 1950, life expectancy at birth in the region was around 51 years, reaching 67 years in 1990 and over 70 years in 2010 (ARRIAGA & DAVIS, 1969; PALLONI& PINTO-AGUIRRE, 2011; BARRETO et al., 2012).

This paper examines the modal age at death (M) and in the interquartile range (IQR) in Brazil and in its states, by sex, between 1980 and 2010, to discuss regional and gender differences in mortality in the country. Given that there are few studies on regional variations in Brazil with respect to the rectangularization of the survival curve and the compression of mortality, the present work aims to shed light on these topics at the sub-national level. Gonzaga, Queiroz, and Lima (2017) estimated IQR and C-50 for a series of Latin American countries; they show a rapid process of the compression of mortality for females, reduction of the IQR, and a stagnation for males, mainly due to the increase in external causes of deaths in recent years. Gonzaga et al. (2009) analyzed the variability in age at death in the state of São Paulo and observed two distinct periods, one with increase in the variability (1980-1995) and one marked by decrease in variability (1995-2005). Gonzaga and Costa (2016) focused on the regional differences in Brazil between 1980 and 2010. They observed the rectangularization of the survival curve was more expressive for women and in the south and southeast regions.

Brazil is an interesting case study to the analysis of convergence or divergence process in mortality, since it is marked by huge regional and social inequality (UN, 2016, MEDEIROS et al., 2015). It is important to understand how such differences relate to trends and differences in adult mortality. There are several studies about trends in infant and child mortality (BARUFI et al., 2012), but much less is known about adult mortality (DUARTE et al., 2002; GONZAGA & SCHMERTMANN, 2016). We are also interested in understanding whether there is a convergence or divergence in adult mortality in Brazil. This is relevant because changes in life expectancy in the near future could be heavily explained by differences in adult mortality as infant and child mortality have shown signs of convergence in recent years (BORGES, 2017; DUARTE et al., 2002). Understanding how those processes are evolving may help in prevention of the challenges they pose to the society as a whole.

Literature Review

According to Wilmoth (2000), longevity gains are, probably, the most important achievement in human history. The linear extension in human lifespan means that mortality gains should not be seen as a sequence of great revolutions but as regular progressive evolution (OEPPEN & VAUPEL, 2002; VAUPEL, 2010). In rich countries, mortality reduction in the first half of the last century was concentrated at young ages. Since 1950, mortality decline was more expressive in older ages (HORIUCHI et al., 2013; OEPPEN & VAUPEL, 2002). Consequently, we saw a deceleration in life expectancy evolution since the 1950's and a rise in the maximum lifespan registered (CANUDAS-ROMO, 2008; HORIUCHI et al. 2013; VAUPEL, 2010; WILMOTH, 2000, 2002; RAU et al., 2008).

This trajectory was different in most developing countries. Since the 1950's, most of those countries experienced rapid mortality decrease (PALLONI & PINTO-AGUIRRE, 2011). Cutler et al. (2006) argued that the decline in mortality in the developing context since the end of Second World War (WWII) was consequence of the knowledge accumulated in 200 years in rich countries. In 1950, the forerunners in mortality decline in Latin America and the Caribbean (LAC) had life expectancy at age five of about 58.7, comparable to Norway in 1900 (PALLONI & PINTO-AGUIRRE, 2011). Mortality decline at older ages in LAC, according to Palloni and Pinto-Aguirre (2011), traced a faster path than the observed in rich countries. Life expectancy at age 60 among LAC forerunners countries grew linearly in the period between 1925 and 2000. Among the laggards, since the 1980 decade, the rate of gain e^o_{60} accelerated. In the same sense, Borges (2017) observes that mortality decline in ages above 60 contributed substantially to the rise in life expectancy in Brazil, especially for women, since the 1980-1991.

Since life expectancy at birth is highly sensitive to mortality variation at younger ages, in rich countries context, it might not be the best indicator to study longevity gains and the aging process (KANNISTO, 2001; HORIUCHI et al., 2013). According to Cheung and Robine (2007), the main feature of the life expectancy is its high sensitivity to infant and child mortality. Although, such characteristic loses importance when the analyses refers to adult and elderly mortality (CHEUNG & ROBINE, 2007). Another drawback related to life expectancy is its inability to inform the origin of the mortality change (CANUDAS-ROMO, 2010).

The mode, the most common length of life in a given mortality regime, is a good indicator for ageing and longevity and is free from arbitrary age limit definition (KANNISTO, 2001). According to Horiuchi and colleagues (2013), the fact that longevity gains are concentrated on higher ages gives greater analytical meaning to the modal age at death. Over time, the differences in life expectancy and modal age at death trends indicate that they are reflecting different aspects of mortality decline (CHEUNG & ROBINE, 2007).

The mortality reduction impact on mean, median, and mode depends on the age at which such improvement happens (CANUDAS-ROMO 2010). Mortality decline in ages before the mode will make the number of survivors (and consequently the number of deaths) higher in some ages, still the number of deaths will not be greater than the amount observed at the modal age at death. Since more survivors will reach age M, consequently more deaths will be registered at this age (CANUDAS-ROMO, 2010). In the same sense, a rise in M implies mortality reductions in ages above the mode. In order to obtain a higher number of deaths in a given age (above M), enough survivors have to live up to then (CANUDAS-ROMO 2010).

The death distribution by age in a given mortality regime is bi-modal (KANNISTO, 2001; CANUDAS-ROMO, 2010). The first mode is observed at age 0, while the second mode is placed in advanced ages. In high mortality countries, the number of deaths at age 0 is higher than in older ages, although it is not the case for most countries these days (KANNISTO, 2001; HORIUCHI et al. 2013; CANUDAS-ROMO, 2008). In Russia and in other countries like Brazil (for males), the increase in mortality for young adults might generate another mode. However, still, it was lower than the old age mode (CANUDAS-ROMO, 2008; CANUDAS-ROMO, 2010).

As the probability of surviving to higher ages rises, the survival curve becomes rectangular. Related to this process, the compression of the mortality makes the age at death distribution more concentrated in a narrower interval, as we observe a reduction in the age at death variability (WILMOTH & HORIUCHI, 1999). The compression of the mortality hypothesis, originally presented by Fries (1980), assumed that there was a limit in human longevity (BERGERON-BOUCHER et al., 2015). According to Wilmoth and Horiuchi (1999), the rectangularization of the survival curve does not mean that there is, necessarily, a limit in longevity. However, if there is a limit in

human life extension, the reduction of mortality would necessarily lead to the rectangularization of the survival curve (WILMOTH & HORIUCHI, 1999).

Wilmoth and Horiuchi (1999) argued that the expressive extension of human life and reduction of the variability in the age at death have influence on how individuals structure the way they live. Variability in the age at death, measured by the interquartile range (IQR), reduced expressively since mortality decline started. They described the dynamics of the IQR variation by mortality reduction by age group. If mortality declines in ages below the first quartile, IQR diminish since the first quartile will be placed in a higher age, compressing the age at death distribution. Mortality declines in ages above the first and below the third quartile increases IQR, since it lengthens the age that marks the third quartile. Once populations achieved moderately low levels of mortality, the percentiles of the distribution of ages at death raised in parallel (WILMOTH & HORIUCHI, 1999).

Canudas-Romo (2008), Cheung & Robine (2007), Cheung et al. (2009) observed, that the compression of the mortality curve stopped in countries with low mortality, while the modal age kept rising. The shifting of the mortality curve hypotheses, formulated by Boongarts (2005), refers to the shifting of the pattern of the force of mortality, while its shape does not change. In this process, while the curve is shifting, the force of mortality falls maintaining the same age profile, while the survival curve shifts to the right (CANUDAS-ROMO, 2008; BERGERON-BOUCHER et al., 2015). Based on the analyses of six low mortality countries, Canudas-Romo (2008) observes that the shifting of the mortality curve may well describe the current pattern of mortality change in several countries.

The literature on the modal age of death considered mainly mortality changes in countries with low mortality (CANUDAS-ROMO, 2008; CANUDAS-ROMO, 2010; OUELLETTE & BOURBEAU, 2011; OUELLETTE et al., 2012; KANNISTO, 2000; KANNISTO 2001). Yet, there is a lot of heterogeneity. Canudas-Romo(2008) and Ouellette & Bourbeau (2011), for example, observed that the USA had the less concentrated age at death distribution. France and Japan presented the highest value of M (CANUDAS-ROMO, 2008). Ouellette et al. (2012) looked at the rectangularization and compression of mortality process in the Canadian provinces. They observed that there was an upward trend in the modal age in all provinces. Although, the regional

disparities remained practically the same in the period analyzed. At the same time, there were reductions in life expectancies differentials between provinces (OUELLETE et al., 2012).

In the USA, the differentials in mortality between states are quite expressive. Such internal disparities may explain why USA lags behind countries with similar development levels (WILMOTH et al., 2011; Fenelon, 2013). In the USA, considering life expectancy at age 50, between 1950 and 2000, the difference between the best and worst achieving state passed from 4.5 to 4.4. In the two last decades of the 20th century, the pace of expected remaining year of life of the richest half of American population (above age 50) is comparable to that of other developed countries. At the other side, since the 1980's, mortality among the poorest stagnated (WILMOTH et al., 2011; EZZATI et al., 2008).

Edwards and Tuljarpurkar (2005) decomposed the age at death and its variability by income and schooling. Individuals in underprivileged situation presented lower age at death and higher variability. However, even after the exclusion of poorer individuals, variability of the age at death in the USA was higher than in the other countries analyzed. When it comes to gender differentials, Removing external causes reduce the age at death variability gap dropped by less than one tenth. Several authors tried to analyze sex differentials in health and mortality and observe that it might be a combination of biological, behavioral, social factors, and their interaction (CRIMMINS et al., 2010; PRESTON & WANG, 2006; GLEI& HORIUCHI, 2007).

Background: mortality changes in Brazil

Given its internal inequality, Brazil may be a good example on how such differences may affect mortality trends and differentials. Brazil is 10th most unequal country, measured by the Gini coefficient (UN, 2016). To illustrate the magnitude of such inequality, Alagoas (AL), a northeastern state, had in 2014 a 0.667 Human Development Index (HDI), lower than countries like Bolivia (0.674) or El Salvador (0.680). At the other extreme, Distrito Federal HDI's was 0.839, close to the value observed in Hungary (0.836) or Portugal (0.843) (UN, 2016).. Life expectancy at birth (both sexes) in Brazil in 2016 was 75.8 (IBGE, 2017). Distrito Federal had in 2016 the 3rd highest life expectancy at birth (78.1) - among 27 states, while Alagoas had the 24th

(71.6). In the same year, the highest life expectancy was registered in Santa Catarina (79.1), located in the South region with the third highest HDI (0.813), and the lowest was observed in Maranhão (Northeast) – the 25th HDI (0.678).

Another way to frame regional disparities in Brazilian mortality is to look how the causes of deaths are distributed. Leite et al. (2015), based on the Global Burden of Disease (GBD) for Brazil, considering 2008 data, observes that the group I of causes - infectious-parasite diseases, maternal and newborn conditions and nutritional deficiency - was responsible for 13.2% of the DALY (Disability-adjusted Lost Years). Regionally, however, there are important differences. In the Northeast and North regions, the same group of causes was responsible for 15.7% and 18.3%, respectively, of the DALY lost in those regions. In the South and Southeast regions, at the other extreme, the group I of causes represented 11.1% and 11.4% of the DALY lost. Those causes of death are closely related to the level of development (BARRETO et al., 2011).

Borges (2017), using estimates from different authors, illustrates how Northeastern (among the poorest) and Southeastern (among the richest) life expectancy differential evolved since 1940's. For males, in 1950 life expectancy at birth in the Southeast was 13.3 years higher than in Northeast, the highest gap registered. In 2000, regional gap among males was 3.4 years (the lowest). Another divergence took place between 2000 and 2010, when life expectancy gap between those regions rose to 4.9. In that period, several northeastern states experienced rise in external cause deaths, what may explain such pattern (BORGES, 2017; WAIZELFISZ, 2013). Considering female life expectancy at birth, Borges (2017) presents moments of convergence and divergence between the Southeastern and Northeastern regions. From 1940 to 1960, e^o differential rose by 2.3 and reached its maximum (9.8). A period of convergence was observed from 1960 to 1980 years, when the regional gap was equal to 7.0. Another divergence occurred between 1980 and 1991. Since then, life expectancy differential among those regions took another convergence path and reached its minimum (3.5) in 2010.

Since the 1980's, reduction in infant mortality contributed the most to life expectancy rise in Brazil (SIMÕES, 2001; BORGES, 2017). The changes are related a series of governmental actions implemented since the 1970's. From 1991 to 2010, for males, middle-aged adults contributed significantly to mortality decline (BORGES, 2017). For females, Borges (2017) argues that the same age group showed a more regular and

significant path, driven mainly by reduction in the circulatory system related deaths. The same author observes that mortality decline in cardiovascular diseases in ages above 60 contributed, as well, to the rise in female life expectancy. Along with the male external causes deaths, may explain gender life expectancy differentials (BORGES, 2017; SIMÕES, 2001). For women, above 80 years old contribution to life expectancy gains were higher than the observed in age 0 between 2000 and 2010 (BORGES, 2017). Borges (2017) found out that that picture is concentrated, more expressively, in the South and Southeast regions.

Young-adult violent deaths pattern, however, varied regionally as well. Borges (2017) shows in the Southern and Southeastern regions young adult mortality contributed negatively to life expectancy changes in 1980-1991 and 1991-2000, while the same trend was not identified in North and Northeastern. Between 2000 and 2010, however, the picture was the opposite. In the North and Northeast young adult mortality change contributed negatively to life expectancy, while the South and Southeast the negative contribution ceased (BORGES, 2017). Waiselfisz (2013) observes in that in all but one state (Pernambuco) in the Northeast region, homicide rates rose between 2001 and 2011, in the North region the same cause of death rose 75% in the period. Between 2005 and 2015, in six states in the North and Northeast regions homicide rate rose more than 100% (IPEA, 2017).

In Brazil, there are few studies of the compression, rectangularization and shifting of the mortality. There are signs that epidemiological and demographic patterns are converging to those observed in developed countries, although we know little about regional differences (GONZAGA & COSTA, 2016). Gonzaga and Costa (2016) observed that the rectangularization of the survival curve and the compression of mortality processes are more advanced in the southern and southeastern (the more socioeconomically developed) regions and among females. Kanso (2014) found similar results: the rise in the modal age at death was more expressive for women and female presented lower variability in the age at death. For the state of São Paulo, Gonzaga et al. (2009) identified that the modal age at death showed two different paths. For females, the mode rose between 1980 and 2000 and then diminished until 2005. The pattern for males was practically the same; the difference is that it rose until 1995 and shrunk since then.

Data and Methods

We make extensive use of the Ministry of Health Mortality Database (Datasus). Datasus collects information on mortality by age, sex and cause of death in all municipalities of the country and it is public available at www.datasus.gov.br. Using Tabwin (Datasus data analysis software) the number of deaths can be downloaded by single age from 1979 to 2015 by gender and at the local level. We concentrate our analysis on the state level (27). We focus our analysis in the period between 1980 and 2010 in order to use population in census years as the denominator for our rates (MINISTÉRIO DA SAÚDE, 2014). The main limitation of the database is the under-registration of death counts and its variability across states (Queiroz, et.al. 2017).

To estimate the mortality curves by single ages, the modal age at death and IQR we performed a two step-methodology. First, we adjusted mortality levels to the degree of completeness of death counts registration (QUEIROZ et al., 2017; HILL et al., 2009). Age and specific mortality rates (for males and females) were estimated considering a three year moving average in the numerator and the population by single age for every census year (1980, 1991, 2000, and 2010) available at IPUMS¹(Minnesota Population Center, 2017). Then, to generate a smoothed complete mortality schedule by age we applied two methods: Log-Quad (Wilmoth et al. 2012) and TOPALS (Gonzaga &Schmertmann, 2016).

Adjusting for under-registration of death counts

To deal with the undercount of deaths in official registry system we used the Adjusted Synthetic Extinct Cohort (SEG-adj) estimates produced by Queiroz and his colleagues (2017). SEG-adj is a Death Distribution Method (DDM) proposed by Hill et al. (2009) that combines the Growth Balance Method (Hill 1987) and the Synthetic Extinct Cohort (SEG), developed by Bennett and Horiuchi (1981). The authors construct the age distribution of the population based on the number of deaths and the age specific growth rate (QUEIROZ et al. 2017; HILL et al. 2009). The procedure is based on the knowledge that the number of people in age x is equal to the observed number of deaths above age x , adjusted by the age specific growth (QUEIROZ et al. 2017; HILL et al. 2009). In that sense, the number of deaths above x age combined with the specific growth rate provide an estimate of the population at age x . Thus, the ratio of the

¹<https://international.ipums.org/international/sda.shtml>

population above age x estimated from the death count and age specific growth rate and the observed population above age x gives the estimate of the completeness of the death counts in a population (QUEIROZ et al. 2017; HILL et al. 2009).

GGB is built upon the balancing equation from which the difference between birth rate at age x and plus and the population growth rate at age x and above gives an estimate of the mortality rate at age x and plus (QUEIROZ et al., 2017). The completeness of death registration is given by the relationship between the mortality rate estimated from two censuses as described above and age specific mortality rates estimated based on death registry system. An orthogonal regression between those two rates is then estimated, the intercept gives the coverage variation between censuses estimation and the slope of the regression gives the undercount estimate of the death coverage system (QUEIROZ et al. 2017; HILL et al. 2009). From the General Growth Balance, the SEG-adj method uses the coverage variation between censuses estimate (Hill et al., 2009).

All three DDM (GGB, SEG and SEG-adj) consider closed population and, thus, are sensitive to migration (QUEIROZ et al., 2017). Hill et al. (2009) suggest dealing with that issue by choosing an age group that is not much affected by migration. That is the choice Queiroz and colleagues (2017) did, from whom we use estimates in the present work.

Adjusting Mortality age profiles

The first method applied for mortality estimation was the system of mortality tables developed by Wilmoth et al. (2012). The log-quadratic model (LQ) estimates a complete set of age specific mortality rates using as inputs the probability of dying before age five (0q5) and the probability of death between age 15 and 60 (15q45). The method allows, as well, the estimation based only on the infant mortality parameter, since it is a mortality indicator present in most countries (WILMOTH et al., 2012). LQ do not produce an estimate of completeness of death counts coverage, but allows one to estimate full age profiles of mortality with limited or defective data.

Equation 1 formalizes the model:

$$\log(m_x) = a_x + b_x h + c_x h^2 + v_x k \quad (\text{Equation 1}),$$

where $\log(m_x)$ is the log age specific mortality rate, $h = \log(5q0)$ reflects the level of child mortality, k reflects the level of excess adult mortality and is chosen to match 45q15 or other global measure of adult mortality, the other variables are constants in the

model. The x represent each age group (0,1-4,5-9,10-14...110+). As Wilmoth et al. (2012) highlight, only one value of the parameters h and k are used in all ages and, in that sense, determine the level and shape of the predicted mortality.

The main disadvantage with LQ is that the constants (a_x, b_x, c_x) in the model were constructed using 719 life-tables from countries in the Human Mortality Database (HMD)². As its developers pointed out, there are only two developing countries (Chile and Taiwan) among the life-tables considered and only one large country with a non-European majority population (Japan). The experience of those countries might not reflect the experience of less developed countries or countries more ethnically diverse. However, the method is very flexible and one could re-estimate the constants by adding other countries to the database. The main issue is that those additional countries might have data limitation and mortality age-profiles might have been estimated using indirect methods or model life-tables. According to Wilmoth et al. (2012), a tradeoff between accuracy and representativeness is unavoidable.

In our LQ application, once we corrected for the undercount of deaths we estimated age specific mortality rates considering a three-year moving average in the rate numerator. From the set of age specific mortality rates, we estimated life-tables for each sex in each year of analysis (1980, 1991, 2000 and 2010). The input parameters for the LQ(5q0 and 45q15) were then calculated from those life tables by sex for each year for the whole country and by state. We applied the model with the coefficients estimated by Wilmoth et al. (2012) with the HMD data. Since we will apply more than one method, we will be able to analyze and compare potential differences in the results in consequence of that choice. Once the age specific mortality rates from LQ were estimated, we constructed another set of life tables from which our variables of interest were collected (ndx , lx , nqx).

The second method applied to estimate the whole mortality curve for Brazil and it states was the TOPALS regressions developed by Gonzaga e Schmertmann (2016). They propose a Poisson regression method based on a relational model. Their model “builds complete schedules of age-specific rates via mathematical adjustments to a specified standard schedule. Our version of TOPALS constructs a fitted schedule of log mortality rates at ages 0...99 by adding a linear spline function with seven parameters ($\alpha_0 \dots \alpha_1$) to a pre-specified standard schedule. We estimate parameters by maximizing a

² www.mortality.org

penalized Poisson likelihood function for age-specific deaths, conditional on age-specific exposure” (GONZAGA & SCHMERTMANN, 2016, p.632).

As authors observe, their version of TOPALS is not sensitive to the pattern chosen, since mortality estimates change very little with the schedule. Another important feature of the method is that it can handle well when there are zero deaths or people counted in a specific year or age. In the original paper, Gonzaga and Schmertmann (2016) assert that TOPALS can be used in two ways: to estimate complete schedule of log mortality rates in areas where the coverage of vital registration is not a problem and to smooth death rates prior to correcting for undercount. In our work, since the first step was to use DDM estimates to correct for potential problems with registration system, we will use the TOPALS estimates in both ways, approximately. In the cases when we observed zero deaths or population, the model will enable us to have the whole age schedule estimates. At the same time, the TOPALS will give us a smoother mortality estimate in all cases, which is fundamental to calculate the modal age at death precisely (HORIUCHI et al. 2013).

Modal Age of Death and Interquartile Range

From both LQ and TOPALS mortality rates estimation, we derived life-tables specific to sex, year, and location. From the number of deaths by age (d_x) function we calculated the modal age at death, according to Kannisto (2001) proposition, as Equation (2) presents:

$$M = x + \frac{d_{(x)} - d_{(x-1)}}{[d_{(x)} - d_{(x-1)}] + [d_{(x)} - d_{(x+1)}]} \quad \text{Equation (2)}$$

Interquartile range (IQR) measures the size of the age range (between the first and third quartiles of the distribution of deaths) in which 50% of deaths occur around the median age at death. A simple way to calculate IQR is to use a life-table with an initial cohort of size 1 and one only needs the survival function (l_x), which in this case ranges from 0 to 1, where 25% and 75% of the cohort are alive. The difference between the ages of these is the IQR.

Results

Comparison the Log-Quad X TOPALS methods

The first step of the analysis is to compare the estimates for each method. In addition to the variation in M and IQR, we are also interested in evaluating two alternative methodologies to obtain mortality age profiles and how they could impact our results. Table 1 indicates that the modal age at death (M) and the interquartile range were (IQR) are both lower in the Log-Quad than in the TOPALS applications, for all years considered. They show similar trends as Modal age at death increases overtime and there is a reduction in the IQR, indicating concentration of deaths. The results also indicate higher M and lower IQR for females. We argue that log-quad results for Brazil are limited, especially for males due to the high levels of mortality for young adults that do not have similarity in the model life table generate using HMD. TOPALS is insensitive to the choice of model life table and might produce more reasonable results.

Table 1 – Modal age at death, IQR, Brazil, Male and Female, TOPALS and Log-Quad

	TOPALS							
	Male				Female			
	M	IQR	$l(x)=0.75$	$l(x)=0.25$	M	IQR	$l(x)=0.75$	$l(x)=0.25$
1980	79.34	25.36	56.01	81.37	83.15	20.67	64.86	85.53
1991	79.39	24.64	56.73	81.38	83.55	18.80	67.52	86.32
2000	79.85	24.09	58.73	82.82	83.97	18.74	68.45	87.19
2010	81.55	22.98	61.38	84.36	85.31	17.83	70.74	88.57
	LOG-QUAD							
	Male				Female			
	M	IQR	$l(x)=0.75$	$l(x)=0.25$	M	IQR	$l(x)=0.75$	$l(x)=0.25$
1980	75.67	22.56	55.81	78.37	79.33	18.18	64.29	82.48
1991	75.43	21.62	56.94	78.56	80.86	17.11	66.86	83.97
2000	76.18	20.59	58.87	79.46	81.65	16.90	67.75	84.64
2010	77.21	19.60	60.99	80.59	82.73	16.07	69.61	85.68

Source: IPUMS;SIM;IBGE

Figures 1 and Figure 2 show the female and male age at death distribution curve for both methods in 2010, as well as the curve estimated without any smoothing method. Figure 1 shows at the distribution of deaths by age using the two methods and the observed data for Brazil. Log-Quad estimates shows a smaller concentration of deaths

in the young adults ages, compared to TOPALS. That difference is quite expressive. From ages 14 to 40, the LQ curve is posted below the TOPALS age at death distribution, as well as the curve estimated without any smooth. For a small age interval (between ages 40 and 45) both curves (TOPALS and Log-Quad) trace a similar path. From age 46 on, however, another interesting feature of the models comparison become visible: a crossover between the curves. Since that point, the number of deaths by rises at a steeper pace in the Log-Quad application.

Figure 2 shows similar comparison for females. Both curves trace practically the same path from the first age considered (11) until around age 55. From that point on, the LQ age at death distribution rises at a steeper pace and registers a higher number of deaths in the age interval that contains the modal age at death (82). In consequence of the steeper slope in LQ curves, both ages - when the number of survivors (l_x) are equal to 0.75 (Q1) and equal to 0.25 (Q3) – used to estimated the IQR are lower and, consequently, so it is the IQR for both males and females. For females, the differences between LQ and TP are less expressive than observed for males.

Figure 1 – Age at death distribution (ndx), Brazil, 2010, Males, TOPALS X Log-Quad

Source: IPUMS;SIM;IBGE

Figure 2 – Age at death distribution (ndx), Brazil, 2010, Females, TOPALS X Log-Quad

Source: IPUMS;SIM;IBGE

It seems that young-adults mortality is important in the LQ and TOPALS differences. In Figure 2 (Females), the curves start to diverge their path only around age 55. For males, the curves trace a similar trajectory only for a small interval. In both cases, however, the slope in the age at death distribution curves are steeper in LQ estimates closer to the modal age.

Modal Age at Death in Brazil (TOPALS and LQ)

We opt to concentrate our analysis using TOPALS. Figure 3 and Figure 4 present the distribution of deaths by age for the males and females in Brazil. We can see that both curves clearly shifted to the right and that the modal age at death (M) rose. M estimated using TOPALS, for females, was 83.15 in 1980 and 85.31 in 2010 (Table 1). It seems that the compression of the mortality is in progress at least since 1980, and there is no sign that process stopped. Interquartile Range (IQR), the indicator of variability in age distribution considered here, for females, was 20.67 in 1980 and diminished to 17.83 in 2010. That means that 50% of deaths in 2010 was concentrated in narrower age interval. It is clear, as well, in Figure 3 that in 2010 the number of deaths in the modal age at death was the highest, shown by the curves height.

Figure 3 – Age at death distribution, Brazil, 1980-2010, Females, TOPALS

Source: IPUMS;SIM;IBGE

A similar pattern emerges for males (Figure 4). In both cases (for males and females), M rose about 2.2 years in the between 1980 and 2010. For males, M estimated was 79.34 in 1980 and 81.54 in 2010. However, the male age at death distribution show a distinguish feature in the young-adult ages, the high incidence of violent deaths makes visible a local mode (KANNISTO, 2001; CANUDAS-ROMO, 2010). It is important to highlight, as well, that are more deaths concentrated among young-adults in 2010 than registered in 1980. In 2010, there were more deaths registered in the age that contains the mode, as observed for females, as shown by the height of the curves.

Figure 4 – Age at death distribution, Brazil, 1980-2010, Males, TOPALS

Source: IPUMS;SIM;IBGE

Compared to females, male age at death profile begins to increase at younger ages (around 50) and rises at slower pace until it reaches the mode. Another interesting feature in Figure 4 is that there was an expressive reduction in the number of deaths in ages between 25 and 71, comparing the 2010 curve to the others, indicating a reduction of mortality for all those ages. Since it occurred in ages before the mode, such mortality reduction implied in a reduction in the variability in the age at death, as the IQR analyses confirms. IQR estimated (TOPALS) was 22.98 in 2010, 2.38 years lower than it was in 1980 (25.36). Although, at the same time, since the curve shifted to the right, we saw mortality reduction at ages above the mode (CANUDAS-ROMO, 2008).

Comparison of Trends by Gender

We focus our analysis in the first and last year of the series, 1980 and 2010 (Figure 5). In 1980 and 2010, the gap between males and females, practically did not change, it was, respectively, 3.80 and 3.76. However, considering the whole period there was a moment of divergence followed by convergence. Between 1980 and 1991, modal age at death gender gap rose. Since then, the differences in the indicator between sexes diminished.

Figure 5 – Age at death distribution, Brazil, 2010, Males X Females, TOPALS

Source: IPUMS;SIM;IBGE

In relation to the differences in the IQR, we observe a similar pattern. In all years, women showed lower IQR, meaning that they presented smaller variability in the age at death. The convergence/divergence dynamics were the same as in the M scenario. The

gap between male and female IQR rose between 1980 and 1991 and diminished since then, as Table 1 presents. It is important to note that male young-adult mortality rose expressively in that period, what may explain the rise in the IQR gap. In the referred decade, the age that indicates the first quartile Q1 rose 2.7 years for females and only 0.7 for men, besides the substantial diminution in child and infants mortality. The divergence in IQR among males and females would be even greater between 1980 and 1991 if there was not a rise in the women's Q3 from 87.2 to 88.6.

Figures 5, 6 and 7 presents the age at death distribution curve, the age specific probability of death for males and females and the number of survivors by age in 2010 (TOPALS), in order to understand the differences between the curves and how they are related to M and IQR gender gaps. The differences in the age at death distribution curve starts approximately at age 14 (Figure 5) and rises until it reaches the local modal in the age at death distribution for males, around age 20. From that point on, until age 38, the gap in the number of deaths by age diminishes modestly. Since age 39, however, the male proportion of deaths by age rises more rapidly and peaked at age 61. Another interesting feature about age at death gender comparison is the maximum heights that male and female curves reach. For females, age 85 concentrated 0.035 (3.5%) of the deaths, while 0.028 (2.8%) of the males exposed to that mortality regime died at age 81.

Looking at the probability of dying at age x graph (nqx) - in Figure 6 - may help understand this picture better. In 2010, the mortality differential between males and females increases steadily from around age 11 until it reaches its highest point at age 20 (age where the male local mode is placed in Figure 6). The difference in young-adult mortality between males and females is striking. From that point on, the mortality differentials starts to narrow up to the end of the curve. It is important to highlight, indeed, that mortality was never lower for men.

Figure 6 – Probability of dying at age x (nqx), Brazil, 2010, Males X Females, TOPALS

Source: IPUMS;SIM;IBGE

With the last assertion in mind, we can see that the point when the number of female deaths, at age 77, surpasses the number observed in men distribution (in Figure 7) is consequence of a higher number of women reaching ages with higher mortality. The same picture holds for every other year considered in this study (1980, 1991, and 2000). This scenario gets even clearer looking at the survival curves for the same year (Figure 7). At age 77, more than 61% of the female synthetic cohort was still alive, contrasting with 45% of men. At age 18 (Figure 7), the male survival curve presents a steep slope downwards. The number of male survivors falls faster until half of the synthetic population is still alive, when the female curve takes a steeper downward trajectory. Although, women reach that point at more advanced ages.

Figure 7 – Number of survivor at age x (l_x), Brazil, 2010, Males X Females, TOPALS

Source: IPUMS;SIM;IBGE

Regional Mortality Differences

Figure 8 shows age at death distribution for males and females in 1980 and 2010. In 1980, there was much more variation in the age of death distribution by state than observed in 2010. Clearly, for both males and females, there were convergence in the patterns of the death distribution by age. The difference between highest and the lowest M estimates for the states reduced in the period in both sexes. For women, that difference was 9.03 in 1980 and diminished to 3.14 in 2010. The 2010 female curve presents an interesting feature about the age at death distribution: until around age 40, the level of the curves vary very little. It seems that regional divergence in those curves becomes more expressive since that point.

Figure 8 – Age at death distribution, by state, females, 1980 (left) and 2010 (right)

Source: IPUMS;SIM;IBGE

Figure 9 shows that male age at death distribution curves seems to be converging as well. All the 27 states curves are in 2010 closer to each other that they were in 1980. The highest to the lowest difference in M passed from 9.39 to 4.72. Although, the 2010 curve highlights a distinguishing feature of male age at death distribution, there is greater regional variability in young-adult mortality. At the same time as in older ages curves are closer to each other, between ages 15 and 29 the curves seem to have diverged.

Figure 9 – Age at death distribution, by state, males, 1980 (left) and 2010 (right)

Source: IPUMS;SIM;IBGE

We selected two states to take a closer look at the evolution local mode for young-adults males. We show that for Rio de Janeiro and Alagoas where the young-adult age at

death distribution curve showed different trajectories. In Rio de Janeiro (left side in Figure 10), relative to 1980, in 1991 the local mode in those was expressively higher. The 2000 curve showed little or no diminution. However, in 2010 (in purple) the curve is considerably lower in the young-adult ages. In the right panel of Figure 10, we see that Alagoas, among others states, took the opposite path in respect to that specific part of male age at death distribution curve. Alagoas had in 2010 the highest local mode considering all states. As we can see in the same picture, based on the previous years, such a concentration of deaths in young ages is somewhat surprising. Considering the period within which the concentration of deaths in young adult ages rose the most - between 1980-1991 in Rio de Janeiro and 2000-2010 in Alagoas – the Q1 in IQR reduced. Which means that the age that indicates 75% of the cohort was still alive diminished in consequence of the additional observed in such young ages.

Figure 10 – Age at death distribution, Rio de Janeiro (left) and Alagoas (right), males, 1980-2010

Source: IPUMS;SIM;IBGE

Figure 11 shows the modal age at death and the interquartile range for both males and females for all the years in analyses. The first interesting result is that males and females form two separate groups, even considering a 40-year period. Females are more closely clustered, which indicates lower variability between states in respect to the modal age at death and the interquartile range. The female cluster is also posted in a higher position, indicating higher modal age at death for females. Even after expressive diminution in male IQR between 1980 and 2010, most states presented higher male IQR in 2010 than registered for women in 1980.

Figure 11 – M and IQR distribution, by state, female and males, 1980-2010

Source: IPUMS;SIM;IBGE

Differently from what we would expect, in all years analyzed, the highest modal age at death was observed in states that were not among the most socioeconomic developed nor the ones with highest life expectancy. Figure 12 presents the modal age at death by state for all years considered. In 1980, for example, the South and Southeast regions presented the lowest M. Those regions are the more developed and with highest life expectancy.

Figure 12 – M and IQR distribution, by state, female and males, 1980-2010

Source: IPUMS;SIM;IBGE

To investigate the possible reasons behind such phenomenon, we plotted the age specific probabilities of death from two different states, São Paulo and Rio Grande do Norte. The first is the richest state in the country, the second highest HDI (IPEA, 2016) and the third highest life expectancy at birth (IBGE, 2017). Rio Grande do Norte has the 16th highest HDI and the 9th highest life expectancy. Although, in 2010, São Paulo had the 11th modal age at death and Rio Grande do Norte the second highest. In Figure 13, we can that São Paulo presents lower mortality in practically every single age until around age 50, when the curves crosses-over. It seems, like will be discussed in the next session, such result is consequence of age misreporting and/or differences in quality of death registry systems in higher ages and/or selection effect.

Figure 13 – Age specific probability of death, Rio Grande do Norte X São Paulo, 2010

Source: IPUMS;SIM;IBGE

DISCUSSION

In this paper we investigate the evolution of modal age at death and compression of mortality in Brazil by gender and regions. Results showed that in Brazil, for males and females, the modal age of deaths has been rising since the 1980, at the same time as mortality became more concentrated in a shorter age range. Both methods applied, despite their differences, displayed the same picture. So far, there are no signs that the shifting of the mortality curve is the dominant process. Unlike developed countries, Brazil still have to deal with high mortality in younger ages at the same time as we observe decline in older age mortality (BORGES, 2017; CORREA & MIRANDA-RIBEIRO, 2016). Since there was mortality reduction above and below the mode, age at death distribution shifted to the right at the same time as the age at death variability diminished (CANUDAS-ROMO, 2010).

For both sexes, we observed the sharpest rise in M between 2000 and 2010 (Table 1). As already discussed, a rise in modal age at death is consequence of mortality decline in ages above the mode (CANUDAS-ROMO, 2010). There was an expressive reduction in mortality in older age groups for men and women. Borges (2017) identified that mortality decline above age 80 represented important gains in Brazilian life expectancy at birth for males and females in the same period. It is noteworthy, that female

contribution was also quite large (Borges, 2017). Using data from the GBD, França et al. (2017) found similar decline for both males and females in mortality above age 75.

Based on the IQR, we observed that the compression of mortality is happening in Brazil, for both males and females. That result goes in the same direction as Gonzaga et al. (2017) found for Brazil and other Latin American Countries. Differently from the parallel rise in the first and third quartile observed by Wilmoth and Horiuchi (1999) in developed countries context, the IQR diminution was guided by a sharper rise in the first quartile. For males, the period in which the third quartile rose the most was between 2000 and 2010, which goes in the same direction with Borges (2017) that showed that in the period the old age mortality decline was most expressive for males. For women, the TOPAL result shows the 2000 to 2010 period with the more important rise in Q3.

For all estimates, female had higher modal age at death and lower IQR. One of the reasons might be that men have much higher risk of dying from external causes. In Brazil, for each death of a women related to external causes, eight men died (MOURA et al., 2015). There is a lot of regional heterogeneity in sex differentials. Moura et al. (2015) found out that the in the North region the mortality rates are 8.9 times higher for males, while the lowest differential was observed in the South region (6.5). In Figure 5, it is very clear the differences for males and females on the age at death distribution curves at younger-adult ages. Other causes of death, naturally, influence the gender differentials as well. For example, mortality reduction from cardiovascular diseases were the most important for older adults in relation to life expectancy gains between 2000 and 2010 and that decrease was more expressive for women (BORGES, 2017; CORREA & MIRANDA-RIBEIRO, 2017).

Once the local mode that captures male excess mortality in young ages rose, from 1980 to 1991, (Figure 4) it stabilized and did not diminish in the period analyzed, besides the diminution in the proportional distribution of deaths in other ages. Probably, the main reason is Brazil's internal mortality disparities. In most states in the Northeast and North the male local mode rose between 2000 and 2010. At the same time, in the Southeast region, there was a reduction in the concentration of death of young-adults. In Alagoas, in the Northeast, for example, the differences between 2000 and 2010 age at death distribution curves for young adult males are quite striking. Probably, the main

explanation for such pattern the rise in homicide rates, according to Waiselfisz (2013), homicide rate in Alagoas between 2001 and 2011 rose 146.5%.

In states like Paraíba (PB), Ceará (CE), Alagoas (AL), Rio Grande do Norte (RN), among others, the concentration of deaths in that group rose in the more recent decade. In 12 of the 27 states, most of them in the North and Northeast regions, the risk of death for males aged 15-49 rose between 2000 and 2010 (FRANÇA et al., 2017). In Rio de Janeiro, São Paulo and Pernambuco the height of the local mode from 2000 to 2010 diminished. In those states, the period with more expressive rise in violent death mortality was between 1980 and 1991 –Rio and São Paulo - and 2000-2010 in Pernambuco (WAISELFISZ, 2013; CERQUEIRA et al. 2017). From 2001 to 2011, homicide rates in São Paulo and Rio de Janeiro diminished, respectively, 67.7 and 43.9% (WAISELFISZ, 2013). Other causes in the group of external causes may as well have contributed for such high concentration of deaths in the young ages. Moura Neto et al. (2012) observes that mortality by transport accidents rose in most Brazilian states between 2000 and 2010. The four highest increases were observed in Northeastern states (MOURA NETO et al. 2012). Although, according to Waiselfisz (2013), homicides represents the largest share of the external causes deaths.

The LQ estimate was not able to capture the young adult mortality hump for males. The young-adult age at death distribution for the LQ is considerably lower the TOPALS estimate and the curve without any smoothing. Probably, since LQ coefficients are based on HMD data (few non-European countries), and given its input parameters (0q5 and 45q15), the model could not capture the excess mortality observed in young adult ages. Among other models, Sharrow et al. (2014) observed that Log-Quad could not fit the HIV mortality hump in Lesotho, the method produced a high flat pattern in age specific mortality that match an overall level of mortality. It seems that we are handling with same kind of problem in the young-adult male mortality.

TOPALS applications were not sensitive to the mortality pattern chosen and along with model parameters resulted in a better fit to original data (Figure 1 and 2). In all estimates (both IQR and M), TOPALS outcomes were higher than LQ. One potential explanation to the higher modal age in TOPALS could be related to age misreporting. LQ coefficients were based on better quality data, and probably with less problems of age misreporting in higher ages. Which is not the case for TOPALS, since it fits closely to the original data. Age misreporting in higher ages usually underestimates mortality,

independently of the direction of the bias (PRESTON et al., 1999). Preston and his colleagues identified that when ages were overstated mortality, starting at age 55, was lower than it would be if ages were correctly stated and these is the same age when LQ and TP curves starts to diverge for females (Figure 2).

In Brazil, there are clear signs that age misreporting affects old age mortality. Below age 75, Brazil had proportionally higher mortality, in comparison with countries known to have high good quality vital statistics, while, in older ages, mortality was lower (TURRA, 2012). Accordingly, Palloni and Pinto-Aguirre (2011) found that, in most countries in Latin American countries, age is systematically overstated, in both censuses and in death statistics.

The unexpected high modal age at death observed in some states (Figure 12), given their life expectancy and development level, may as well be related to age misreporting differences. As well, it is likely that quality in death registry system may also vary and affect older ages more expressively. There are relevant differences in DDM estimates by states (Queiroz et al., 2017). The crossover in São Paulo and Rio Grande do Norte age specific probability of dying, shown in Figure 16, could also be related to selection effects. These results needs further analyses to be more accurately understood.

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