**Research Note: The role of birth cohorts in recent mortality trends among Mexicans aged 60 plus in urban and rural areas.**

**Abstract:**

Background: The urban mortality penalty in Mexican adults aged 60 and above has been acknowledged in the late 20th Century, hinting a rural advantage. However, few studies have analyzed mortality trends to address whether birth cohorts were related to such discrepancies.

Objective: identify the role of birth cohorts in changes in mortality trends across urban and rural areas in Mexico.

Methods: We used data from the Mexican Health and Aging Study (MHAS). We reconstructed population death rates and exposures from the survivors of the different cohorts between 2010-2021. We performed a set of age-period-cohort models constraining the cohort dimension to determine the role of non-linear (and fully identifiable) cohort effects in urban and rural mortality for Mexicans aged 60 plus.

Results: We found non-linear birth cohort effects highlighting a relative risk of mortality 1.28 (1.08-1.54) times higher than the average trend for males who lived in urban areas and were born between 1930 and 1940, although we could not identify a rural/urban gradient over time. For females, the urban penalty dissipated and was reversed since the 2010s, mostly due to strong linear effects but some identified some cohort effects as well, suggesting that women living in rural areas had a mortality 1.26 times higher (1.06-1.51) for cohorts born between 1935 and 1940

Contribution: The urban penalty found for males was likely associated with cohort effects, hinting that its dissipation could be the beginning of a new trend, based on causes of death that are more likely to affect younger cohorts.

**Keywords:** Mexico, Birth Cohorts, Urban-Rural Mortality, Aging

**Competing interests:** The authors claim no competing interests

Introduction:

Mexico has experienced a rapid process of population aging due to a fast pace of mortality and fertility decline when compared to more longevous countries, accelerating population growth and longevity simultaneously (Palloni et al., 2006; Palloni & Souza, 2013). Despite that, not all individuals have the same opportunities to live long and healthy lives. A differential allocation of wealth, education, location, and other key resources among a given population translates into an uneven distribution of health (Graham, 2004). In Latin America, improvements in living conditions across space have been unequal, historically favoring individuals who lived in cities (Curto de Casas, 1993). Environment is a key determinant in establishing inequalities in health (Dahlgren & Whitehead, 2021; Lynch et al., 2000). This results in a health gradient mostly driven by social aspects rather than biological ones (Braveman et al., 2011; Marmot, 2005). However, the direction of the health gradient may vary. Sometimes individuals who live in urban areas present a higher mortality than their rural counterparts despite better access to health care (urban penalty), but a higher exposure to other risks (Gould, 1998; Reher, 2001). Rural areas often show higher mortality due to greater material deprivation (Cosby et al., 2008, 2019; García, 2020; Murray et al., 2006).

Previous studies have found in Mexico a steady gradient over time favoring individuals aged 60 and above who lived in areas under 100000 inhabitants (Lozano-Ascencio et al., 1996; Martínez-Téllez et al., 2023; Rosero-Bixby, 2018). An urban penalty was also found in Brazil (Costa Monteiro da Silva et al., 2020) and Costa Rica (Rosero-Bixby, 2018; Rosero-Bixby & Dow, 2009). The reasons behind the rural advantage that Mexico’s aging population has are unclear but might be linked to generational behaviors. Previous studies on certain causes of death in Mexico with strong generational components such as lung cancer (Rizo-Ríos et al., 2015; Rojas-Martínez et al., 2019) or diabetes (Dávila-Cervantes & Agudelo-Botero, 2019; Rodríguez-Aguilar, 2018; Rojas-Martínez et al., 2024) have found disparities in mortality due to those causes of death in the last 25 years. Cancer primarily affected pre-1940 cohorts in wealthier Mexican states, while diabetes has increasingly impacted younger generations in poorer states since 2010. In this case, cohort effects would imply that some birth cohorts have a greater risk of dying than others, because of differential environmental hazards or exposure to health behaviors that vary across space.

However, there are no previous studies that explore trends in all-cause mortality specifically from a cohort perspective considering the urban-rural gradient in the country. Therefore, in this research note, we investigated recent mortality trends in Mexico for the aging population and identified possible birth cohorts with a differential risk of dying, since we believe that could provide a better understanding of the dynamics of aging in the country (and possibly the region)

Data:

We used data from the Mexican Health and Aging Study (MHAS). The MHAS is a nationally representative, longitudinal survey that is focused on adults aged 50 years and above living in Mexico. It does not only capture the health status of the population, but also sociodemographic information and other relevant aspects during their life course. The MHAS began in 2001 with a sample of participants born before 1951, and successive follow-up waves and interviews were completed in 2003, 2012, 2015, 2018, and 2021. Refill interviews were carried in the 2012 and 2018 wave for individuals aged between 50 and 59 years.

We used waves 2 to 6 from the MHAS comprehending the mortality period between 2010-2021 in three-year intervals, reconstructing the survivors for the gap 2003-2010 creating new analytical waves based on their mortality information, retrieving year of death from different waves (See Tables 1A and 2A in supplementary material). Similar approaches creating new analytical have been used before in MHAS (Huffman et al., 2019). We assumed that mortality across a given year was proportional between the discrete three-year intervals. Due to cause-of-death inconsistencies in MHAS, we only analyzed all-cause mortality. Overall population exposures during this period were 42076 person-years. This means that we followed up the cohorts’ trajectory for a ten-year period (meaning that we do not have any complete cohorts yet). After some testing, we only considered individuals aged 60 years and above since mortality data is sparse before that age. As the final age group, we considered individuals who reached age 90.

Due to sample size limitations, we grouped all individuals who lived in cities under 100.000 inhabitants into rural city size category and defined the urban population as those who lived in cities of 100.000 and above, like a previous study using the MHAS (Rosero-Bixby, 2018). The analysis was sex stratified. Changes in the status of city size in the years between waves were minimal, and we assumed that deaths occurred in the same city size as previously reported.

Methods:

To establish the contribution of birth cohorts to those differential patterns by urban and rural mortality, we resorted to an age-period-cohort (APC) model based on estimable functions (Carstensen, 2007; Clayton & Schifflers, 1987; Holford, 1992). In a linear model, the three dimensions of age, period and cohort are perfectly collinear, in what is widely known as the linear identification problem (Bell & Jones, 2013). While many strategies were developed that can deal with this limitation, mathematically this issue has not been resolved yet (Bell & Jones, 2014, 2018). However, second-order, non-linear effects for each dimension are identifiable since they are not perfectly collinear. To visualize them, we constrain (remove the effect of long-term trends by constraining the average slope of a dimension into 0, detrending it) one (or two) of the dimensions while attaching the linear drift to the other one. Arbitrary, theory-based decisions can be made to determine to which dimension the linear trend belongs to. In some specific death causes, like certain types of cancers or diabetes, it can be assumed that trends are linearly driven by cohorts (Rojas-Martínez et al., 2019, 2024) since long-term period effects for those causes are unlikely. However, to analyze trends in all-cause mortality this is a probably unjustified assumption (and as a result has been rarely used).

Therefore, we can assume that historically linear changes and improvements in all-cause mortality were assumed to be associated with continuous period changes (based on improvements in nutrition, medicines, or policies that result in better health for all individuals), since life expectancy has grown almost in a linear fashion in Mexico until 2000, before stagnating from the beginning of the so-called “war on drugs” started (Aburto et al., 2016; Canudas-Romo et al., 2017). Furthermore, the COVID-19 pandemic implied a spike in deaths across all population groups, so we believe that attaching linear effects would be better suited to the period dimension in order the explain this dynamic.

The basic forms that we use in this study is the following, present in Equation (1):

(1) : ln(*d*(*a*, *p*)) = *rp0*(*a*) + *δ*(*p* - *p*0) + *g*(*p*) + *h*(*c*)

In which *rp0*(*a*) represents the cross-sectional age-specific death rates of the period of reference (in this case, 2012),  *δ*(d - d0) the linear drift attached to the period dimension + *g*(*p*) non-linear estimable period effects and *h*(*c*) the non-linear estimable cohort effects

The “*Epi”* package was developed in R software (Carstensen et al., 2021) and provided the necessary tools for the analyses and allowed the user to choose among a series of options and parameterizations for modeling. In this model, age, period, and cohort are treated as continuous variables, meaning that graphical results are provided for all values of the three dimensions independently of their grouping. We estimated the effects considering natural-spline models that establish one parameter per value of A, P, and C instead of splines (Carstensen, 2007). We adjusted the splines to seven knots to better approximate the contribution of each singular cohort. To extract the linear drift, we chose the standard naïve weights. To simplify the analysis in this research note, we only focused on the results in the cohort dimension (although the results for the age-specific rates and period effects can be found in the supplementary material)

Results:

Figure 1 presents the age-standardized death rates by sex and city size across each wave since the 2001-2003 period (using the weight of the sum of exposures by age in the sample as the reference population). In the 2001-2003 period, rural and urban males presented similar mortality levels, without any clear-cut tendency until the 2019-2021 period (where urban males presented higher levels). Females who lived in rural areas had a slightly lower age-standardized mortality in 2001-2003 but in the subsequent waves, they had the higher death rates. Additionally, figures 1A and 2A in the Supplementary Material present the age-specific rates by period and cohort for each of these four categories, highlighting those discrepancies that occurred at the highest age groups.

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Figure 1: Age-Standardized Death Rate by Sex and City Size among population aged 60+, Mexico 2001-2020

In Figure 2, we presented the non-linear cohort effects were for each group, comparing the relative risks of each cohort to the average secular trend. Results for the most extreme cohorts should be taken with a grain of salt due to their lower counts and exposures, so we focused the analysis mostly in cohorts born between 1925 and 1955. Males in urban areas born between 1935-40 presented a rate ratio 1.28 (1.08/1.54 with a confidence interval of 95%) times higher than the average trend. This was also the case for the total of males (driven arguably by the increased mortality of the urban group).

For females, we only observed non-linear cohort effects for those who lived in rural areas and were born between 1935 and 1940, with an increase of the relative risk 1.27 (1.06/1.51) times higher than the average trend.

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Figure 3: Non-Linear Cohort effects for all-cause mortality by birth cohort for individuals aged 60+ separately by sex and city size, Mexico.

While non-linear cohort effects are expressed in relative risks, the result of relative risks for all populations is a reasonable reference to analyze mortality trends across cohorts and compare groups, as shown in Figure 4. We observe that some birth cohorts of males in urban areas born between 1935 to 1944 had a higher average rate ratio, and a lower risk than the average between 1930 and 1935 and between 1945 and 1950 (hinting a rural disadvantage). For females, the urban females born between 1935 and 1940 presented a lower risk than the average, which is consistent with the rural disadvantage for that group observed in the previous figure.

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Description automatically generated with medium confidenceFigure 4: Non-Linear Relative Risks of mortality by birth cohort for urban individuals aged 60+ compared to the total population separately by sex, Mexico.

Additionally, Table 3A in the supplementary material presents the period effects (linear and nonlinear altogether) for the APC models compared to the values of the 2010-2012 period, following the secular trend of the last decade. The effect of the pandemic in the 2019-2021 period becomes evident by the heightened relative risk for mortality for males, 1.29 (range between 1.13 and 1.47) times higher than 2010-2012, and mostly affecting males in urban areas, with a relative risk 1.39 (1.21-1.66) times higher. For females, the increase was 1.26 times higher than the reference (1.10-1.44), with a particular increase in rural areas with a relative risk of 1.34 (1.11-1.64)

Figure 3A in the supplementary material presents the results of the age effects for the period-based parameterizations in 2010-2012 and 2019-2021. In all cases, cross-sectional age effects increased exponentially with age, but we do not observe significant differences in log death rates in any period attributable to age effects.

**Discussion:**

Our results contribute to the literature of current mortality trends in Mexico, since life expectancy at birth and older ages has stagnated in the country (Aburto & Beltrán-Sánchez, 2016, Zazueta-Borboa, 2024). Specifically, by investigating differences in cohort mortality among older adults, and the urban-rural inequalities therein. We found the presence of non-linear cohort effects in all-cause mortality for urban and rural populations aged 60 and above in Mexico. We found an increasing linear trend in mortality in the last decade for males, while for females we observed a stable trend that saw an increase in the 2019-2021 period, arguably due to the COVID-19 pandemic.

Males living in urban areas born between 1930 and 1935 presented a higher mortality than the average, indicating that the rural advantage that was observed in previous studies (Lozano-Ascencio et al., 1996; Rosero-Bixby, 2018) is possibly related to that particular cohorts, but probably was countered with cohort effects for some younger cohorts in rural areas (possibly related to metabolic conditions as previously hinted), resulting in similar mortality rates for urban and rural populations (and potentially hinting a new gradient in the future). For females, the urban penalty observed at the baseline was reversed, and while most of it is due to a linear increase in mortality in females from rural areas (which can be observed in Figure 1 and Table 3A), there is a cohort effect in the group between the 1935-1940 birth cohorts.

The increase in diabetes-attributable mortality is likely to explain the link between the increase in mortality and changes in the urban penalty effect. First because is a leading cause of death among Mexican older adults and important driver of life expectancy stagnation, and diabetes detection and treatment has been changing drastically across urban and rural areas (Parker et al., 2018) Since 1990s, food habits shifted from fresh products to ultra-processed food with and higher level of sugar consumption (Monteiro et al., 2018). Diabetes-related deaths likely affected urban areas first, then spread to rural regions, eliminating the rural mortality advantage (especially among younger cohorts).

Among the limitations of this study, we must mention that the Age-Period-Cohort model is an exploratory/descriptive technique to analyze aggregate-level patterns, not looking for causality. Therefore, while we identified differential relative risks in certain cohorts, we are not able to disentangle the drivers behind those additional risks (especially given the lack of cause of death data). While we reconstructed a possible combination of deaths and exposures for the analyzed period in the 2010-2012 period, the MHAS was not conducted between years 2003 and 2012 (even if mortality data was recorded based on date of death). Thus, possible lost-to-follow exposures might have resulted in some undercounting of mortality for that period. Is also possible that the MHAS might have been a bit limited following the mortality in rural areas during the COVID-19 pandemic (potentially meaning that more deaths are registered in the upcoming wave). Furthermore, considering the pattern of cohorts with higher mortality risk (mostly starting at the beginning of each decade), issues with age-declaration might be occurring. Finally, since we do not have complete cohorts we are unable to analyze differential mortality with a summary measure such as life expectancy or standardized rates considering different groups of cohorts (something that could be done in future MHAS waves).

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