**Title: Homicides increased inequality of lifespans in Mexico, 2005-2015**

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**Abstract [Max 250-300 words]:**

**Objective**: To quantify the effect of homicides on life expectancy and inequality of lifespans in Mexico during the upsurge of violence after 2005 up until 2015.

**Design**: Cross-sectional retrospective demographic analysis with publicly available data on mortality by cause of death from the Mexican Institute of Statistics and the Mexican Population Council.

**Setting**:

**Participants**: Aggregated population above age 15 by state (32 Mexican states) and sex over the period 1995-2015.

**Main outcome measures**: Life expectancy and lifespan inequality conditional on surviving to age 15, as measured by years of life lost, with age and cause-specific contributions of medically amenable conditions, diabetes, ischemic heart diseases, and homicides to the changes between 1995 and 2015.

**Results**: Mexican male life expectancy at age 15 increased more than twice as fast in 1995-2005 (1.17 years) than in 2005-2015 (0.55 years). Lifespan inequality reduced by more than half a year for males between 1995 (14.31) and 2005 (13.77). Between 2005 and 2015, the reduction (-0.15) was about four times smaller. Homicides had the largest effect on slowing down male life expectancy and increasing lifespan inequality in 2005-2015 over ages 15-49. At the state level, some states experienced reductions in life expectancy in 2005-2015 particularly in the North. In the same period five states showed a large increase in lifespan inequality (Chihuahua, Nuevo León and Tamaulipas --all bordering with Texas in the US, Sinaloa and Durango). Although the increase in homicide mortality affected lifespan inequality in all states after 2005, one state in the South was affected the most (about 1 year increase in for males and about two months for females in Guerrero).

**Conclusions**:

**Introduction [~ 4000 words, 3579 now]**

**What is already known on this topic?**

Latin America is the most dangerous region in the world. In Mexico, life expectancy stagnated in the decade 2000-10 due to the unprecedented rise in homicides after 2005 and a continuous increase in diabetes mortality. At the state level, the effect of violence was such that Mexican states lost life expectancy gains in the period 2005-10.

**What this study adds?**

Studying lifespan inequality adds an important dimension to population health to assess heterogeneity in lifetimes at the population-level and uncertainty in the timing of death at the individual-level. This study reveals that the Mexican population not only is living less, on average, but it is also facing more uncertainty in their age at death due to the increase in homicidal violence. Men living in the North of Mexico face the largest uncertainty in length of life. As a result, inequality in lifespans has increased rather than decline in recent years.

Violence has become a major public health issue in Latin America since the end of the 20th century.1 This region currently experiences the highest homicide rate in the world (over 16.3 per 100,000 people), with some countries in Central America, including Mexico, undergoing an upsurge in homicides since the first years of the 21st century.2 In Mexico, for example, homicide rates doubled between 2007 and 2012 (from 9.3 to 18.6).3 As a result of this increase, along with an increasing burden of diabetes, male life expectancy in Mexico stagnated in the period 2000-10.4 At the subnational level, gains in life expectancy due to causes amenable to medical service throughout 2000-10, such as infectious, respiratory diseases and birth conditions, were wiped out by the increase of homicide and diabetes mortality in each of the 32 states in Mexico, with large regional variations.5

Trends in life expectancy are important and have been studied in Mexico and its states.4-6 However, life expectancy masks substantial heterogeneity in individual mortality trajectories,7 8 referred here as lifespan variation. Variability in ages-at-death has arisen as an important topic since it addresses the growing interest in health inequalities.9 10 Studying both life expectancy and lifespan variation adds an important dimension to the study of population health because these indicators represent individuals’ decisions based not only on their expected lifetime, but also on the uncertainty in their timing of death.11 Most studies have found a negative association between these two measures, suggesting that as life expectancy increases, variation in lifespans decreases.8 12-14 However, at the subnational level increases in lifespan variation may simultaneously occur with increases in life expectancy, mostly due to a slowdown in mortality improvements in working ages (e.g., premature mortality).15 16 This is particularly relevant for countries that have experienced an upsurge in homicides, since this increase has mainly affected working age individuals.

In Mexico, for example, homicide mortality is concentrated between ages 15 and 50, affecting mainly males.3 We thus hypothesize that the Mexican population may be experiencing increases in lifespan variation due to the rise in homicides in tandem with declines in overall life expectancy at the subnational level. We also expect larger changes in lifespan variation among men and uneven variability across states in the country due to the changing dynamics of violence and homicides in Mexico.17 For instance, states in the Northern part of Mexico (e.g., Chihuahua, Durango and Sinaloa) experienced the largest losses in life expectancy due to homicides between 2005-105 and it is likely they also exhibited large lifespan variation during that period, although this impact may now be larger in other states as homicides spread throughout the entire country in recent years.18 However, since the more pronounced fluctuation in age-specific mortality occurred over working ages,5 it is unclear what the net effect would be on lifespan variation but it certainly had an effect on premature mortality. On the other hand, there have been mortality improvements in causes amenable to medical service, which have been Mexico’s priority since the 1990s (e.g., infectious and respiratory conditions).19 20 These improvements could have a substantial effect on reducing variation in lifespans, particularly in historically poor states, which are mostly concentrated in the South.

This paper makes three main contributions. First, it contributes to the literature on lifespan variability and inequalities in health in the context of rising homicides. Most literature in this area focuses on social determinants of health (e.g., socioeconomic status and health risk factors) as proximate determinants of lifespan variability and health inequality.10 In contrast, our paper highlights the role of violence, and its ultimate consequence in the form of homicides, among young adults on increasing lifespan variability. A second contribution is its focus on Mexico. Mexico is experiencing a growing violence associated with the war on drugs that started in the last decade, making the increase in homicides a serious health policy concern.5 18 Understanding the consequences that homicides have on population health is important for policy makers in Mexico and in other countries that are experiencing similar increases in homicides such as Honduras and El Salvador in Central America, and Venezuela in South America.2 Finally, this analysis contributes to our knowledge of regional variation in lifespans.

In this article we use two indicators computed from age 15, life expectancy (e15) and ‘years of life lost’ () as an indicator of lifespan variation.21 These measures allow us to thoroughly analyze premature mortality, and they also have an important public health interpretation as e15 estimates the expected average years to be lived above age 15 while quantifies the average life expectancy loss attributable to death.22 We analyzed how these indicators changed over a 20-year period, from 1995 to 2015, for females and males in Mexico and its 32 states, and determined the ages and causes of death that contributed the most to the observed changes.

**Study data and Methods**

We used data on deaths from vital statistics files publicly available through the Mexican National Institute of Statistics.23 These data include information on cause-of-death by age, sex, and place of occurrence from 1995 to 2015. Additionally, we used population estimates corrected for completeness, age misstatement, and international migration available from the Mexican Population Council to construct age-specific death rates by age, sex and state.24

***Cause-of-death classification***

We classified deaths into eight categories according to previous studies targeting the main causes of death in Mexico5 25 using the concept of Amenable/Avoidable mortality (AM). 26 27 This concept assumes that there are some conditions that should not cause death in the presence of timely and effective medical care. Deaths due to these conditions are used as a proxy for the performance of health care systems.26

The first category includes conditions amenable to medical service. It refers to mortality that could be reduced by primary or secondary prevention and timely medical care (for example, birth conditions, infectious and respiratory diseases). We separately analyzed diabetes, ischemic heart diseases (IHD), lung cancer, cirrhosis, and road traffic accidents because the first two are leading causes of death in Mexico,4 and all of them are amenable to health behavior and medical service.5 The last (eighth) category includes residual causes of death labeled ‘Residual’ (see Supplemental Material for specific details on deaths classification). To mitigate biases due to misclassification of causes of death, we focus on deaths occurring below age 95 since cause-specific coding practices above that age are less reliable due to the presence of comorbidities.

We study two comparable 10-year periods, between 1995 and 2005, and from 2005 to 2015. This allowed us to identify a period of mortality improvements (1995-2005) in which life expectancy increased by 2.1 and 4.3 years for males and females, respectively,24 and homicide rates declined among young adults.28 The second period (2005-2015) is characterized by stagnation in life expectancy,4 particularly for males (at around 72 years) and slow progress for females (from 76.7 to 77 years), accompanied by an unprecedented rise in homicide mortality.5

***Lifespan variation indicator***

Several dispersion measures have been proposed to analyze lifespan variability.8 29 In this study, we use as a dispersion indicator and we refer to it as “lifespan variation” from age 15. It is defined as the average remaining life expectancy at age 15 when death occurs, or life years lost due to death.13 21 For example, if in a cohort of newborns all die at the same age then the value of is zero; to the extent that death occurs at different ages, those who die “prematurely” will die before their expected lifetime contributing lost years to life disparity. We study lifespan variation conditional on surviving to age 15 to capture the onset of homicides and the young mortality hump. In lifetable notation, is defined as:

where and are the survival function, the force of mortality, life expectancy, the age at death distribution at age , and the open-aged interval, respectively.

This indicator was chosen because it has three main properties: it is easy to understand, to interpret, and to decompose thereby allowing us to quantify the impact of age and cause-specific mortality on changes in lifespan variation over time.22 30 An additional advantage is the high correlation between and other measures of variability in ages at death (e.g., variance, or the Gini coefficient) which suggests that our main results would be consistent with those obtained with any of these additional measures.29

***Demographic and statistical methods***

To mitigate random variations in cause-of-death classification, we smoothed cause-specific death rates over age using a 1-d p-spline separately by year, sex and state.31 We then rescaled the smoothed cause-specific deaths to all-cause death rates to maintain the overall mortality level by year, sex, and state. Using these mortality rates we computed period life tables for males and females by year-state in the study period (1995 to 2015) following standard demographic methods.32 Finally, we computed life expectancies (e15) and life disparities () and estimated the age- and cause-specific contributions to differences between the periods 1995-2005 and 2005-2015, using standard decomposition techniques.33 All analyses were carried out using R34 and are fully reproducible from the Supplemental Material. In addition, to analyze state-specific mortality profiles and changes along other period from 1995 to 2015 we created an interactive app to perform sensitivity analyzes available [here](https://demographs.shinyapps.io/lv_in_mexico/).

**Results**

**Changes in life expectancy and lifespan variation at the national level**

As expected, results for males show the largest impact of homicides on life expectancy and lifespan variation for both time periods (Figures 1-4). We thus focus on these results (results for females are shown in Supplemental Material, figures S1-S4).

Figure 1 shows age- and cause-specific contributions to the change in male life expectancy at age 15 between 1995 and 2005 (Panel A) and between 2005 and 2015 (Panel B). Vertical values enclosed in rectangles next to the y-axis represent age-specific contributions (in years), while the length of the bars correspond to cause-specific contributions by age (also in years). Overall cause-specific contributions across all ages are shown in the panel’s legend in parenthesis (in years).

Among men, life expectancy at age 15 increased more than twice as fast in 1995-2005 (1.17 years) than in 2005-2015 (0.55 years). Most causes of death contributed to the improvement in life expectancy in 1995-2005 (except for diabetes, heart disease and accidents) implying that their underlying mortality rates reduced over the period. Importantly, homicide rates declined in 1995-2005 and this contributed to about one-fourth (0.44 years) of the overall gain in life expectancy in this period. Moreover, about 80% (0.36 years) of this contribution was due to reductions in homicide mortality between ages 15-49 (red bars in Figure 1, panel A). In contrast, the slowed down improvement in life expectancy in 2005-2015 was mainly the result of rising rates of homicide and heart disease (panel B), hence their negative contributions to the change. Contrary to the previous decade, about 98% (-0.29 years) of the negative contributions due to homicides resulted from worsening mortality rates between ages 15-49. Results for women suggest a continuous improvement in life expectancy over time with a negligible impact of homicides; in fact, homicide rates continuously declined since 1995 (Supplemental Material, figures S1-S4). For example, female life expectancy increased by 0.58 year in 1995-2005 and by an additional half year of life in 2005-2015; all these resulted from mortality improvements in most causes of death, except for diabetes and medically amenable conditions (e.g., infectious and respiratory diseases). These results clearly show the impact of homicides on average length of life with a particularly detrimental effect among young males.

[Figure 1 about here]

Figure 2 shows results for lifespan inequality () in both periods. This figure depicts information in a similar format to that in Figure 1. Panel A of Figure 2, for example, shows that lifespan inequality reduced by more than half a year between 1995 (14.31) and 2005 (13.77). This means that, on average, Mexican males were losing about half a year of life less at their time of death in 2005 than in 1995. Although lifespan inequality also declined between 2005 and 2015 (-0.15), the reduction in 1995-2005 was about four times larger. In other words, male lifespan inequality was stagnant in recent times. Nonetheless, improvements in other causes of death contributed to a reduction in life span inequality in both periods; for example, mortality declines in accidents and cirrhosis at younger ages. Importantly, cause-of-death contributions clearly show that homicides and amenable causes of death had the largest effect on increasing lifespan variation in 2005-2015 (e.g., positive contribution). For example, homicides and conditions amenable to medical service account for most of the reduction in between 1995 and 2005 (about -0.28 and -0.12 years, respectively); however, between 2005 and 2015, rising homicide rates contributed to widening lifespan inequality (about 0.17 years at ages below 60). For females, lifespan variation decreased since 1995. There is a tipping point at around age 70 indicating the importance of cardiovascular disease, diabetes and medical services at older ages in reducing lifespan inequality, while accidents, homicides and cirrhosis play a larger role at younger ages. These results underscore the major role of rising homicide rates among young adults in recent times and the consequent slow improvement in reducing lifespan inequality.

[Figure 2 about here]

**Changes and cause-specific contributions to life expectancy and lifespan variation at the state level**

In previous sections, we identified the importance of homicides on slowing the improvement in life expectancy at age 15 and in reducing lifespan disparities. These results, however, masked important differences at the state level. Figure 3 shows changes in life expectancy (panel A) and in lifespan inequality (panel B) for males in each of the 32 states in Mexico between 1995 and 2005 (blue dots) and between 2005 and 2015 (red triangles). We grouped states into three broad regions to facilitate interpretations of results, North, Central and South. There are two main results. First, life expectancy among males had a larger increase in 1995-2005 than in 2005-2015 across all states (panel A), but some states experienced reductions in life expectancy in 2005-2015 particularly in the North (e.g., Chihuahua, Nuevo León and Sinaloa). Second, lifespan inequality (panel B) was reduced in most states over the two decades, 1995-2015, except for states in the North. For example, every state between 1995 and 2005 had major improvements in reducing lifespan inequality of at least 0.4 years of life, particularly those in the South of the country (e.g., Chiapas, Oaxaca and Puebla), but between 2005 and 2015, all states in the north had very low reductions in lifespan disparity with five states having a large increase in lifespan inequality (Chihuahua, Nuevo León and Tamaulipas --all bordering with Texas in the US, Sinaloa and Durango).

[Figure 3 about here]

We further assess the cause-of-death contributions by state to lifespan inequality (Figure 4). We focus on the main causes of death including causes amenable to medical service (AMS), diabetes, homicides, and road traffic accidents. For contributions from all cause-of-death categories and females’ results see Supplementary Material figures S4-S7.

Results suggest that, except for one state in the North (Baja California Sur) and one in the central part (Tlaxcala), every state decreased lifespan inequality due to improvements in medically amenable causes of death and homicides between 1995 and 2005. As we hypothesized, the states showing the larger reductions were mostly concentrated in the southern region of Mexico (e.g., Chiapas, Oaxaca, Puebla, Guerrero and Morelos). A decade later (2005-2015), however, there is more heterogeneity on the contribution of causes of death to life span inequality. For example conditions amenable to medical service contributed to reductions in lifespan inequality in most states, while homicides increased it also in most states. Although the increase in homicide mortality affected lifespan inequality in all states after 2005, one state in the South was affected the most (about 1 year increase in for males and about two months for females in Guerrero), followed by some states in the North (increase of about 0.5 and 1.0 year in in Chihuahua and Sinaloa) and in the central part of the country (e.g. Colima). Mortality due to diabetes shows negligible contributions to life span inequality in both periods. Results for females (Supplementary Material figures S4-S7) indicate substantial reductions in lifespan inequality due to AMS with somewhat smaller contribution from diabetes and IHD in the overall period 1995-2015.

**Discussion**

Our results show an important impact of homicides on the Mexican population from 2005 to 2015. Improvements in male life expectancy and lifespan inequality at age 15 slowed down relative to the trend observed in the previous decade, during which young males experienced an increase of more than one year in life expectancy and a decrease of more than half a year in lifespan inequality. Our research sheds some light on this national trend by showing that the unexpected rise of homicides after 2005 was the main contributor that held back life expectancy and reductions in lifespan inequality.

*The effect of homicides on life expectancy trends*

Despite major public health interventions between 2005 and 2015, such as the enactment of a universal health insurance program (*Seguro Popular*),35 every state in the country experienced less progress in life expectancy at age 15 than in the previous decade. Our findings clearly indicate that the spread of homicides throughout the country after 200518 was the main contributor to reduce life expectancy gains for males between 2005-2015. This is consistent with previous research documenting the impact of homicides between 2000 and 2010.4 5 Despite recent efforts from the Mexican government to contain the upsurge of violence in the country,36 37 our results using data up to 2015 clearly indicate that life circumstances among young adults have not improved and are actually deteriorating. For example, about 1 of every 4 states in the country (8 states out of 32) experienced a reduction in life expectancy at age 15 and this occurred across all regions of the country. The strongest effect of homicide on life expectancy occurred in Guerrero, a state in the Southern region, were life expectancy was reduced by almost 2 years between 2005 and 2015, followed by Chihuahua and Sinaloa in the North, with life expectancy losses of one year of life each, three additional states in the North (Zacatecas, Baja California Sur and Nuevo León), one in the Central region (Colima), and one in the South (Morelos), experienced losses of half a year in life expectancy over the same period.

*The effect of homicides on lifespan variation trends*

Our results further show that homicides have slowed down progress on reducing life span inequality among young adults in Mexico. While lifespan inequality ( declined by more than half a year between 1995 and 2005, a decade later this progress was stagnated and barely reached a reduction of less than two months in recent years (2005-2015). Increase in homicide mortality accounted for most of the stagnation on life span inequality; importantly, the effect was concentrated in the young population, between ages 15 and 50, which is consistent with the high sensitivity of lifespan variation to premature mortality.13 Thus, males in Mexico not only live less on average, as shown by life expectancy, but they also face more uncertainty in their time of death due to the increase in homicides. In addition, the same states that experienced a reduction in life expectancy after 2005 also showed an increase in life span inequality due to homicides (five states in the North bordering Texas in the US --Chihuahua, Nuevo León, Sinaloa, Durango and Tamaulipas-- and one in the central region --Nayarit). These results are consistent with the upsurge in violence in these parts of the country. Although homicides have spread across the country,17 they are not evenly shared between states and over time. By 2010, the North of Mexico was the region most affected by homicide mortality.5 In contrast, by 2015 all regions show similar patterns of the effects of homicide mortality in lifespan inequality. Moreover, while in 2010 Chihuahua (Northern region) was the state affected the most by homicide mortality relative to the 2005 level, in 2015 Guerrero (Southern region) has overtaken this place. The impact of violence in the population in these states is staggering. To put it in perspective, in 2010 males aged 15-25 in Chihuahua had 3.1 times higher mortality rates than the US troops in Iraq between 2003 and 2006.5 Recent evidence suggests that the second and fifth most dangerous cities in the world are located in the state of Guerrero, along with cities in countries with higher homicide rates than Mexico.38 As a result, young males in Guerrero experienced an increase in lifespan inequality of almost an additional year due exclusively to homicides. In other words, males in Guerrero are prematurely dying at an average of one year younger. Moreover, increasing lifespan inequality underscores increasing inequality within states. These results indicate that homicides are an additional contributor to health inequalities in the country, which complement previous evidence identifying rising health inequalities between states as a challenge for Mexico.6

The increase in homicide mortality after 2005 suggests a rapid deterioration in life expectancy,5 in perceived vulnerability and psychosocial outcomes,39 and, as we show, in lifespan inequality in the Mexican population. This means that after 10 years of the beginning of the so-called War on Drugs, the Mexican government has not been able to reduce homicidal mortality and its effects, at least to the levels observed back in 2005.

Mexico stands today in a situation in which the consequences of the ongoing violence represent an urgent priority for comprehensive strategies to mitigate the impact on population health. In an international context, Mexico’s levels of violence are not even the highest around the globe, nor the region. Countries in central America, such as El Salvador and Honduras, and Venezuela, Colombia and Brazil in south America have higher homicide rates. Given the great level of lifespan variation and life expectancy losses in Mexico, it is likely that countries in the region experience higher variation in lifespans and reductions in average life due to homicides. Our results from Mexico, underscore the need to assess the impact of violence on population health and in the uncertainty surrounding the age at death in other countries from Latin America and their regions.

**Funding**

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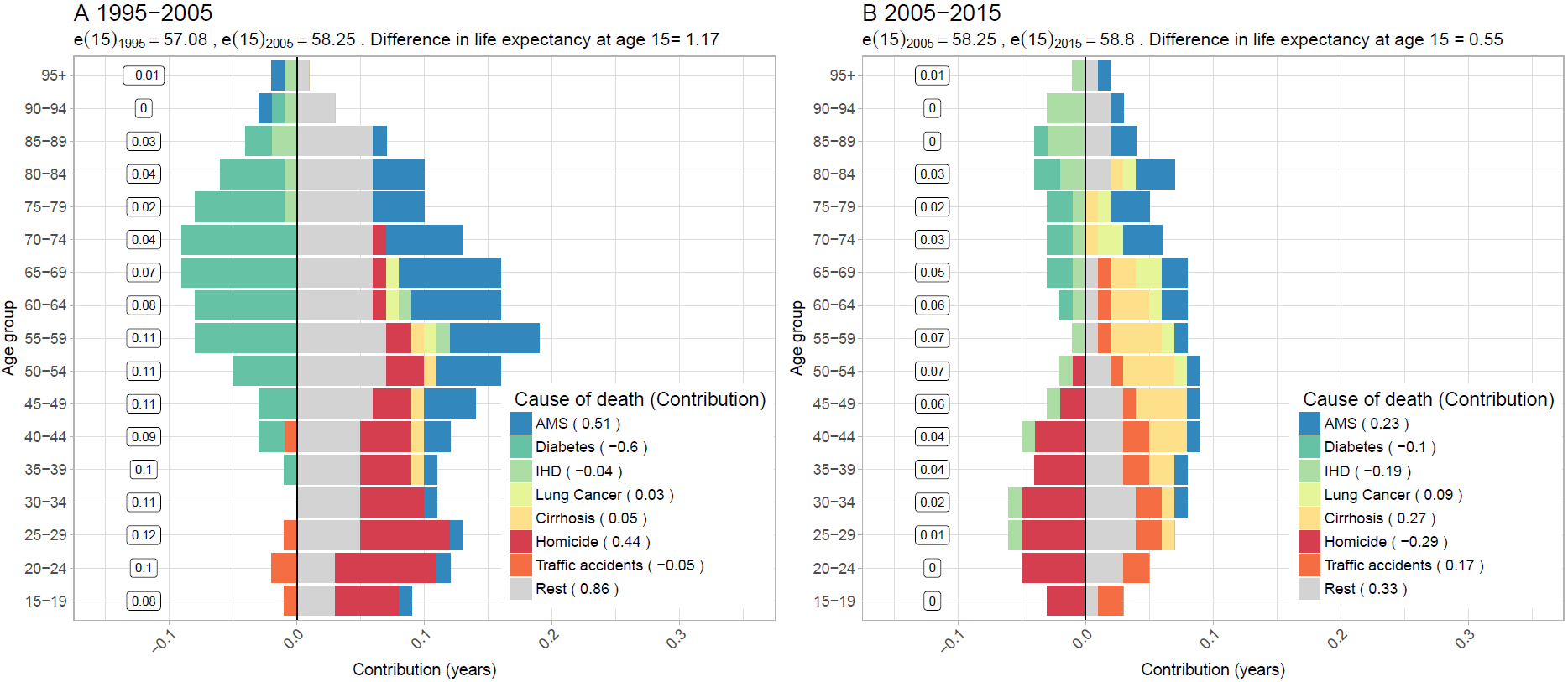
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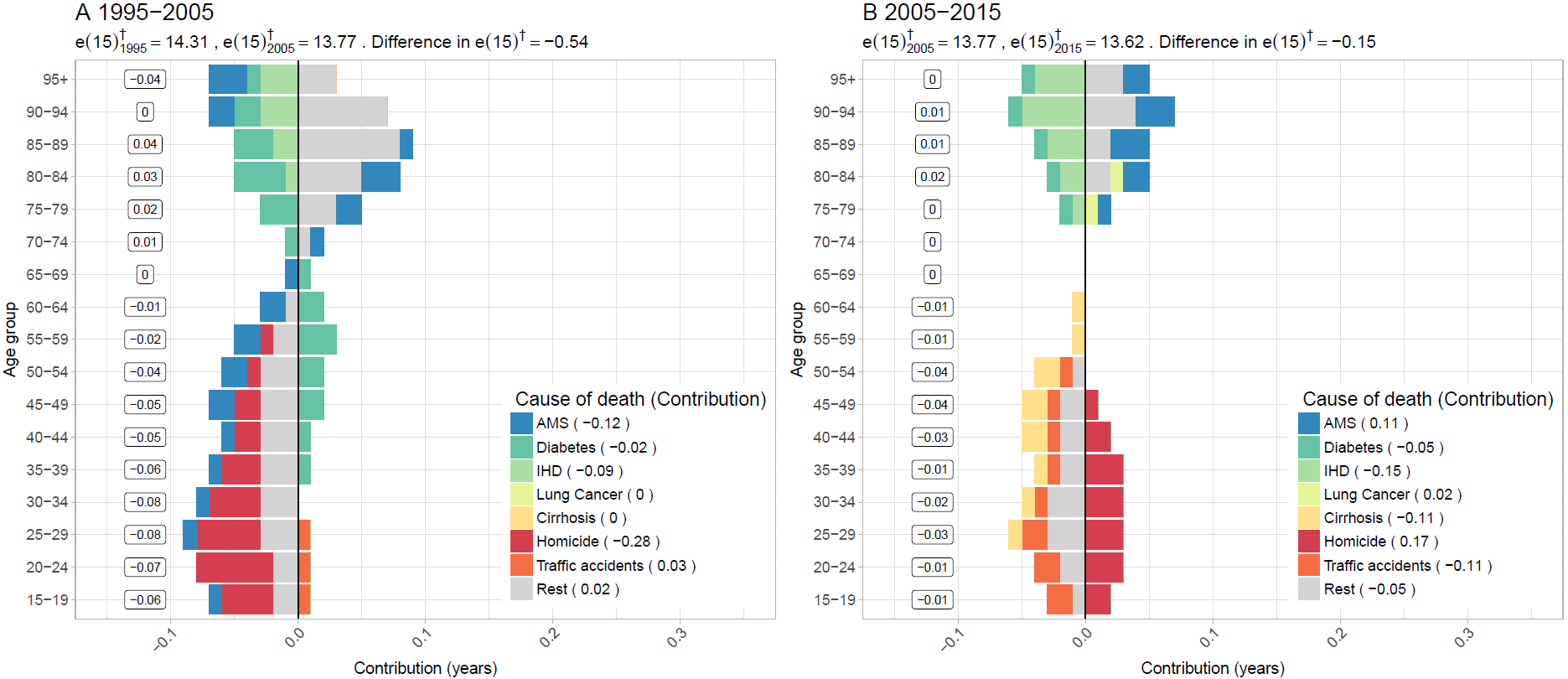
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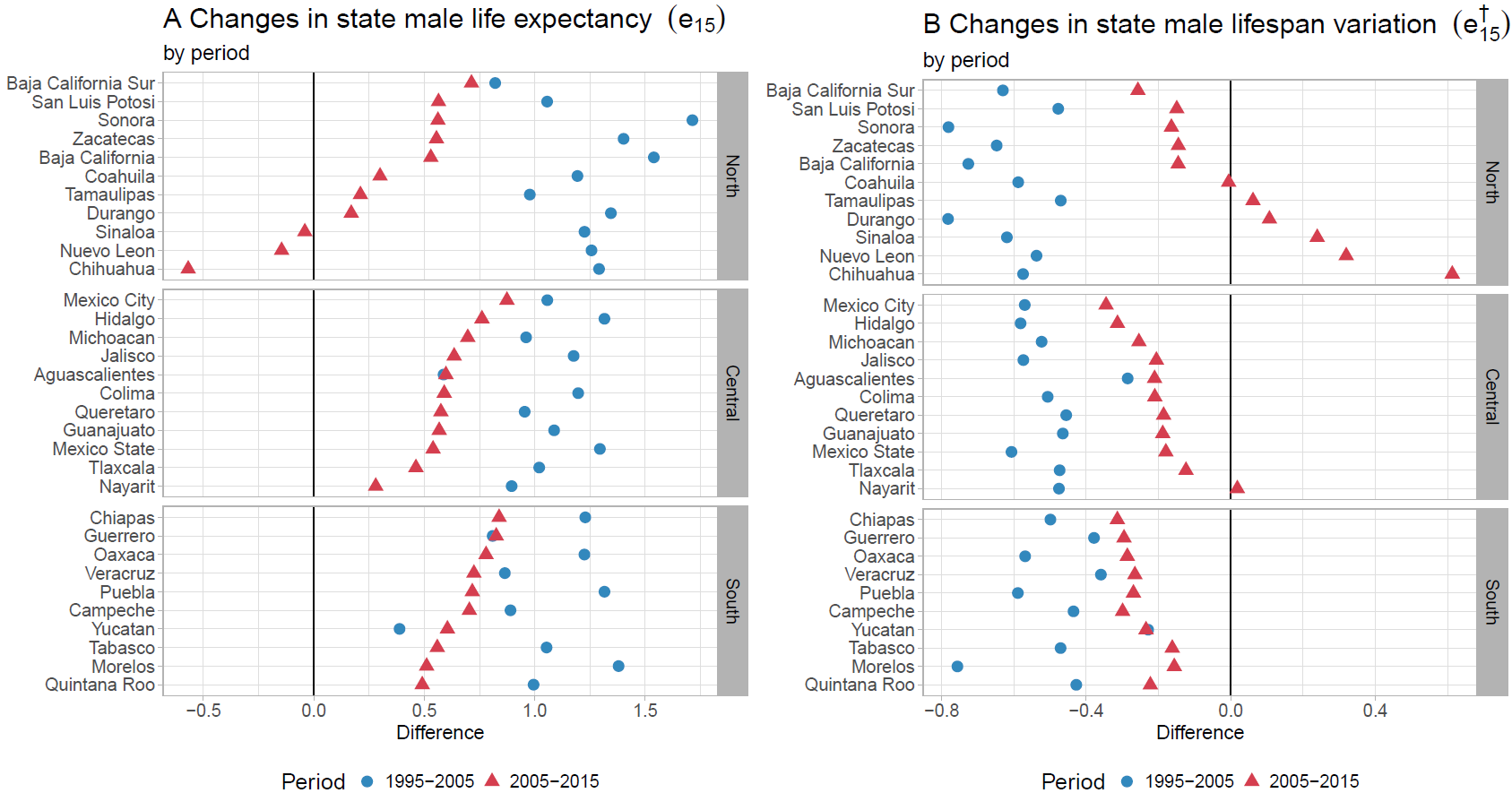
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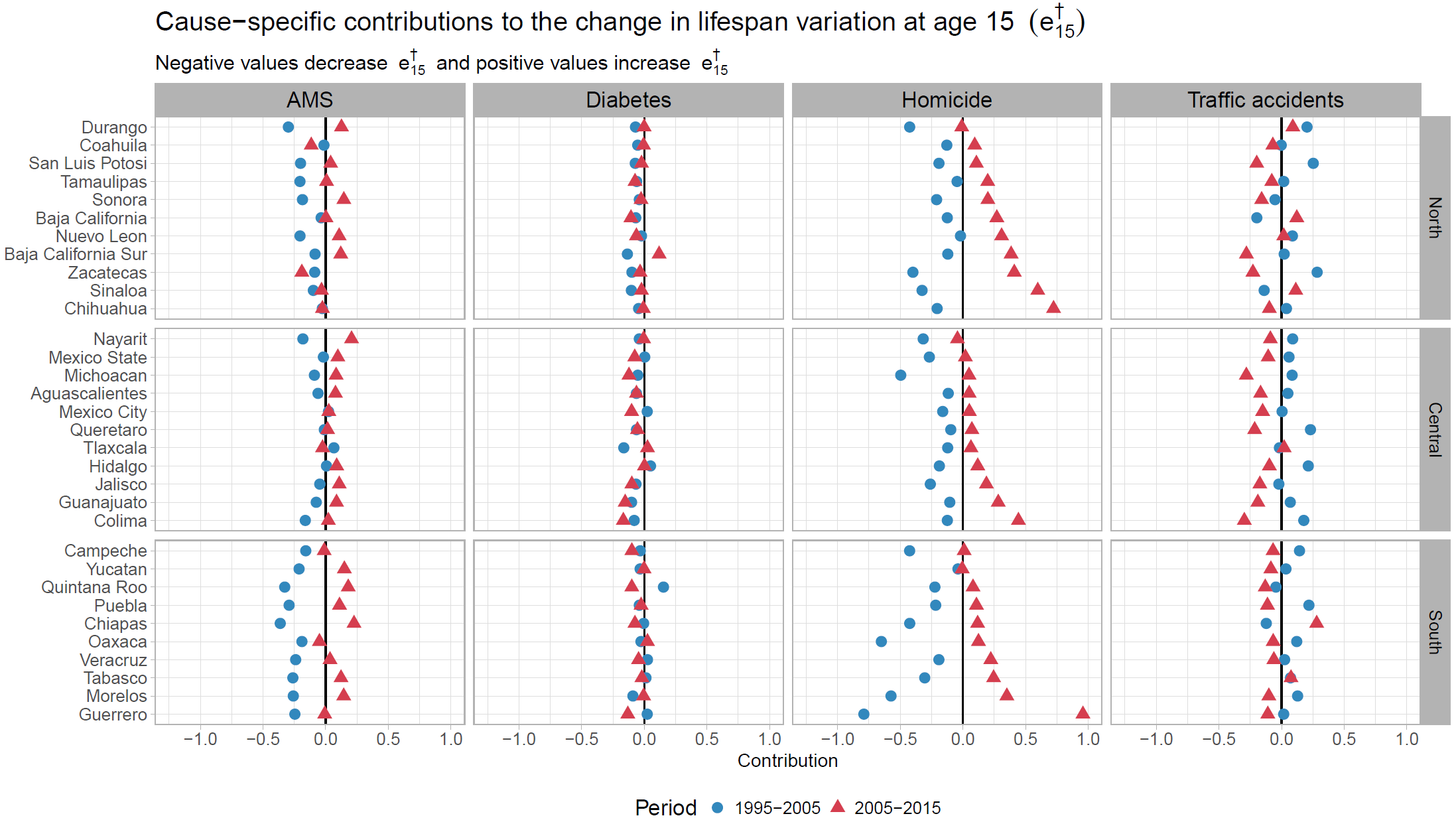
**Tables and Figures**

**Figure 1. Age-cause specific contributions to the changes in national life expectancy (**e0**) for males. Panel A refers to 1995-2005 and panel B to 2005-2015. Note: Numbers in boxes are age-specific contributions.**

**Figure 2. Age-cause specific contributions to the changes in national lifespan variation () for males. Panel A refers to 1995-2005 and panel B to 2005-2015. Note: Numbers in boxes are age-specific contributions.**

**Figure 3. Changes in male life expectancy (**e0**) (panel A) and male lifespan variation () (panel B)**

**by state for the periods 1995-2005 and 2005-2015.**

**Figure 4. Cause-specific contributions to changes in male lifespan variation () by state for the periods 1995-2005 and 2005-2015.**