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Inequalities in lifespan in Mexico, 1990-2015: deterioration in adult survival

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Complete List of Authors:	Aburto, José Manuel; Syddansk Universitet Det Sundhedsvidenskabelige Fakultet, Biodemography Unit, Department of Public Health Riffe, Tim; Max-Planck-Institut fur Demografische Forschung Canudas-Romo, Vladimir; Australian National University College of Arts and Social Sciences
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Authors: José Manuel Aburto, *PhD student* (JMA)[a*†], Tim Riffe, *Research Scientist* (TR)[b†] & Vladimir Canudas-Romo, *Associate Professor* (VCR)[c]

Author affiliations:

[a] Institute of Public Health-Unit of Biodemography, University of Southern Denmark, Odense 5000, Denmark.

[b] Max Planck Institute for Demographic Research, Rostock 18057, Germany

[c] School of Demography, Australian National University, ACT 0200, Australia

[†] These authors contributed equally to the paper

[*]The manuscript's guarantor.

Corresponding author: José Manuel Aburto: jmaburto@health.sdu.dk, T: +45 65509416

Keywords health inequalities, adult health, causes of death, mortality

Abstract

Objective: To quantify the effect of medically amenable conditions, diabetes, ischemic heart diseases, lung cancer, cirrhosis, homicides and road traffic accidents on longevity in Mexico during 1990-2015.
Design: Retrospective demographic analysis using publicly available aggregated data.
Setting: Vital statistics from the Mexican civil registration system.
Participants: 64 populations (32 Mexican-states by sex) with data on causes of death.
Main outcome measures: Cause-specific contributions to the gap in life expectancy in three age groups (0-14, 15-49 and 50-84) with a low-mortality benchmark based on the lowest observed mortality in Mexico.
Results: The population below age 15 shows improvements in survival. Average survival below 15 over states was 14.82 (95% confidence interval, 14.76 to 14.88) and 14.78 years (14.70 to 14.86) in 2015, for females and males respectively. However, the adult population aged 15 to 49 shows deterioration among males after 2006 in almost every state due to an increase in homicides and a slow recovery thereafter. Out of 35 potential years, females and males live on average 34.57 (34.48 to 34.67) and 33.80 (33.34 to 34.27), respectively. Adults aged 50 to 84 show an unexpected decrease in the low mortality benchmark, indicating nationwide deterioration in both females and males with average survival of 28.59 (27.43 to 29.75) and 26.52 (25.33 to 27.73) out of 35, respectively. State gaps from the benchmark were mainly caused by ischemic heart diseases, diabetes, cirrhosis and homicides. We find large health disparities between states, particularly for the adult population after 2005.
Conclusions: Mexico has succeeded in reducing mortality and between-state inequalities in children. However, the adult population is becoming vulnerable as it has not been able to reduce the burden of conditions amenable to health services and violence. This has led to large health disparities between Mexican states in the last 25 years.

Strengths and limitations of this study

- In the second half of the twentieth century Mexico experienced great progress in reducing mortality at early ages, but homicides rates more than doubled after 2005.
- We introduce a methodology to quantify the impact of medically amenable mortality and behavior related conditions on life expectancy relative to a low mortality benchmark.
- We analyze patterns in life expectancy for different age groups over time (1995-2015) and simultaneously account for changes in causes of death and inequality between states that have undergone major social and public health transitions.
- Mortality data from Mexico are likely to present inaccuracies in cause-of-death classification due to comorbidities, particularly at older ages.
- Our estimates regarding homicide mortality are likely to be underestimated due to inaccurate practices regarding counting, reporting, and due to the large number of missing individuals in Mexico

Introduction

The second half of the 20th century was marked by sizable improvements in mortality, living conditions, and health in most Latin American countries.[1] In Mexico, these improvements have slowed down recently due to opposing trends in particular causes of death. For instance, homicide and diabetes increased during the first decade of the 2000's, even as infectious and respiratory diseases continued to fall over the same period. While life expectancy at birth increased by 4.3 years for males (from 67.6 to 71.9) and 3.4 years for females (from 73.8 to 77.2) between 1990 and 2000,[2] between 2000 and 2010, life expectancy at birth entered into a period of stagnation for males and slowed progress for females.[3]

This period coincides with ongoing public health interventions, such as the Universal Vaccination Program and stablished health systems (IMSS, ISSSTE), and with the implementation of a Universal Health Coverage program (*Seguro Popular*). The latter program provides primary and secondary health care to the uninsured population and allocates funds to cover catastrophic health expenditures.[4] Further, since 1997 conditional cash transfer programs were introduced to supply incentives for poor families to invest in education, health, and nutrition.[5] Some evidence suggests that Mexico experienced substantial decreases in infant and child mortality, and in the prevalence of acute malnutrition between 1980 and 2000 thanks partially to these interventions.[6] Similarly, by 2012 *Seguro Popular* had provided health insurance coverage to an additional 52 million people in Mexico (or 44.4% of the population), leading to increased access to public health care and protection from the financial consequences of disease.[7]

Conditional cash transfers have focused on the poorest states, and *Seguro Popular* was introduced at different times in different states across the country. Although these actions underscore broad progress in public health interventions, they mask disparities between Mexican states and the epidemiological patterns for different age groups. For instance, Mexico faces a rapid aging process in which the interaction between infectious diseases and noncommunicable conditions can be anticipated in the adult population[i].[8] Therefore, it is necessary to assess the varied impacts that these interventions may have had on mortality in Mexican states at different ages.[9]

One approach to approximate the impact of health care and other interventions, and to reveal potential areas of improvement is by operationalizing the concept of Avoidable or Amenable Mortality (hereafter abbreviated AM).[10 11]This categorization of mortality aims to measure the quality of health service systems by selecting certain causes of death that should not occur in the presence of effective and timely health care. Therefore, improvements in AM mortality are expected over time, as has been observed in several countries. For example, among 19 industrialized countries, including 14 countries from Western Europe, USA, Canada, Australia, New Zealand and Japan, a reduction in AM rates was observed over the past 20 years.[10] Avoidable mortality rates fell, on average, by 17% for males and 14% for females in these countries between 1997 and 2003. However, the USA lagged behind the other countries in this group, while Japan, France and Australia were the top performers. Despite mortality reductions from cancers and circulatory diseases for both sexes, disparities between countries persist, with the United States showing the smallest reductions (around 5%) for both sexes.[10]

In Mexico, the components of avoidable mortality had different trends since the late 1990's. Mortality from infectious diseases and nutrition-related conditions decreased between 2000 and 2004,[12] while deaths related to diabetes and ischemic heart diseases increased in the first decade of the 2000s.[13] Importantly, increases in the latter causes of death were concentrated in the poorest states of the country.[13]

We extend previous analyses by using the most recent available data to study mortality trends by cause of death for all 32 Mexican states, by sex, and over the full period from 1990 to 2015. This choice of period covers several public health interventions and captures several major trends in state and cause-of-death variation. We further segment AM into health intervention-related and behavior-related AM causes that capture the epidemiological patterns of Mexico.[14] In addition, our work differentiates from earlier studies by comparing state mortality patterns with an easy-to-understand low-mortality benchmark calculated for large age groups (i.e. 0-14, 15-49 and 50-84). This concept has been previously used in mortality studies.[15-17] Deviations from the low-mortality benchmark indicate a strong potential for improvement.

We hypothesize age-dependent variations in mortality outcomes. In particular, we expect convergence between states and improvement in survival for young people, since public health interventions are mainly focused on infant and child health. For instance, the vaccination program and *Seguro Popular* aim to fully cover children in the entire country, and recent evidence suggests a decrease in mortality below age 15 due to a decline in infectious and respiratory diseases.[18] On the contrary, we expect little improvement in survival for the young-adult population due to the sudden and egregious rise in homicide mortality.[19] We foresee health deterioration among older adults due to documented increases in diabetes mortality.[18] Although every state has the commitment to provide universal coverage and equitable access to health care, we anticipate disparities in mortality improvements between states due to heterogeneous epidemiological transitions among states,[20] and differences in how health care programs have been delivered to the population.[21]

Data sources & methods

Our analyses are based on publicly available anonymized datasets. We used death register microdata files produced by the Mexican Statistical Office (INEGI) for years 1990 to 2015.[22] From these data, information on causes of death by single age, sex, and state of residence at the time of death was extracted. Population estimates from 1990 to 2015 came from the Mexican Population Council (CONAPO).[23] These population estimates adjust for age misstatement, undercounting, and interstate and international migration. Death counts and estimates of the population exposed to risk were used to calculate cause-age-specific death rates by sex for each state from 1990 to 2015.

Classification of Causes of Death

To classify deaths we use the concept of "Avoidable/Amenable" Mortality (AM).[10 11] We group causes of death into eight categories based on previous classifications that has recently been adapted to the case of Mexico.[14] The first category refers to those conditions that are susceptible to medical intervention, such as infectious and respiratory diseases, some cancers and circulatory conditions, and birth conditions, among others. It is labeled "Causes amenable to medical service". We separate diabetes, ischemic heart diseases (IHD), lung cancer, and cirrhosis as subcategories of AM because these causes are susceptible to both health behavior and medical service, and because the first two represent major causes of death in Mexican adults.[20] Likewise, we separate homicide and road traffic accidents because they have emerged as leading causes of death among young people, and the first one recently had a sizeable impact on life expectancy in Mexico [14]. Remaining causes were grouped into a single category labeled "Other causes".

Death data were originally classified according to the International Classification of Diseases (ICD), revision 9 for years 1990 to 1997 and revision 10 for 1998 to 2015 (see Additional file 1 Table 1 for details on ICD codes for each category). To check the validity of these cause-of-death codes in Mexico, we performed a sensitivity analysis and did not find major ruptures in mortality trends by AM classification (See Additional file 1, Figure 1).

Comorbidity in the old age population has increased in Mexico.[24] As a result inaccuracies may arise in cause of death registration due to problems associated with medical diagnosis, and selection and coding of the main cause of death. Although analyses in these ages should consider multiple causes of death to better represent old age mortality, it is out of the scope of this study since we focus on the primary cause of death. We truncate our analysis at age 85 to avoid misinterpreting results related to inaccurate cause of death coding practices.

Age groups

We calculate life expectancy in three large age groups to capture mortality differences along the life course. Life expectancy in each age group simply refers to the average years of life lived between two ages conditional on survival to the lower age bound. This measure is also known in demographic analysis as temporary life expectancy.[25] The first age group refers to people aged 0-14. This group is likely to represent improvements in causes amenable to medical service (e.g. infectious diseases and conditions of perinatal period).[3] The second group, aged 15-49, is used to capture the effect of homicide mortality and external causes historically related to the young-adult mortality hump, as well as maternal mortality for women.[26] This age group had an important impact on changes in state life expectancy in the first decade of the 2000s.[14] The third group covers older adults aged 50-84; with similar life expectancy (ages 40-84) used for international cancer comparisons.[27] Older adults are likely to represent a vulnerable group due to deterioration in non-communicable diseases and injury-related mortality in recent years.[20 28]

Low mortality benchmark

Our low-mortality benchmark is calculated on the basis of the lowest observed mortality rates over all states by age, year, cause, and sex. Subsequently, life expectancies are calculated with these rates. This represents the highest potentially achievable life expectancy from the aggregated low mortality profiles. This benchmark is a practical reference because it is based neither on a projection of improvements into the future nor on an arbitrary and likely dissimilar population. The resulting minimum mortality rate schedule has a unique age profile, and it determines our benchmark temporary life expectancy. It can be treated as the best presently achievable mortality assuming perfect diffusion of the best available practices and technologies in Mexico.[17]

Methods

Cause-specific death rates are the basis of all calculations in this work. To mitigate random variations, these rates are adjusted in two steps. First, we smooth cause-specific death rates over age and time for each state and sex separately using a 2-d p-spline.[29] Second, we rescale the smoothed cause-specific death rates to sum to the raw all-cause death rates for each sex and state. Period life tables up to age 84 for males and females from 1990 to 2015 and their benchmarks were calculated following standard demographic methods.[30] Temporary life expectancies were calculated [25](see Additional file 1 for a technical overview) and cause-specific contributions to the difference between each state and the low mortality benchmark were estimated using standard decomposition techniques.[31] Finally, the coefficient of variation of the gap between temporary life expectancy in each age group with the low mortality benchmark was calculated to measure the level of disparity between states over time. This indicator is relative and has the property that even if temporary life expectancy refers to different age-ranges, i.e. 0-14,15-49, and 50-84, the values are still comparable over age-groups and time. In addition, we performed two-way ANOVA and post hoc tests to analyze disparities in temporary life expectancy between states and age groups in Mexico.

Patient involvement

No patients were involved in setting the research question, outcome measures, design of the study. No patients were asked to advise on the interpretation of the results and there are no plans on disseminating the results of this research to study participants or the relevant patient community.

Results

Trends in life expectancy for Mexican states by age-groups

Figure 1 presents the temporary life expectancies by state for three large age groups: the youngest (ages 0-14), young adults (15-49) and older adults (50-84), over the period 1990-2015. Grey lines refer to each of the 32 states; the black lines represent the average over states; and the blue lines represent the low mortality benchmark. The black line at the top of each panel indicates the maximum livable years in each age group: 15 for the youngest, and 35 for young and older adults conditional on surviving to ages 15 and 50, respectively. Any gap between a state line and the blue line represents potential additional years of life if mortality were to achieve the low mortality benchmark.

All states show improvements in the youngest age group since 1990, approaching the low mortality benchmark, which itself is very close to maximum survival below age 15. This was observed even in the southern states such as Puebla, Chiapas and Tabasco which have lagged in reducing mortality at these ages throughout the entire period.

Life expectancy between ages 15 and 49 shows a sudden drop after 2005 among males in almost every state in Mexico. In 2005, young males in this age group had a temporary life expectancy of 33.9 years (95% CI, 33.5 to 34.2) averaged over states. By 2010, the number of states below this level had increased from 14 to 23. Chihuahua, Sinaloa and Durango, in the northern region, experienced a substantial mortality shock in 2010 in this age group, and consequently recorded the largest departures from the low mortality benchmark. In 2015, the state average (33.8 years, 33.3 to 34.3) had almost recovered to its 2005 level. Trends for females are closer to the low mortality benchmark.

Among older adults, life expectancy between ages 50 and 84 shows stagnation and deterioration over the entire period of observation. Even the low mortality benchmark exhibits a gradual downward trend, pointing to a generalized mortality increase. The female state average life expectancy declined from 28.8 years (27.4 to 30.2) in 1990 to 28.3 years (27.4 to 29.2) in 2010. By 2015, this average only managed to recover to 28.6 years (27.4 to 29.8). Among males, the average over states decreased from 26.7 years (24.7 to 28.8) in 1990 to 26.3 years (24.9 to 27.6) in 2010, and 26.5 years (25.3 to 27.7) in 2015. Furthermore, we fitted three linear models to both sexes, combined and independently, and the slope coefficient was significant in all of them at the level of $p < .005$. These results suggest that the decline observed was significant. As with young adult males, some states experienced deterioration after 2005, with a minor recovery since 2010.

[Figure 1 about here]

Health disparities between states and age groups

Figures 2-5 show results for males because they exhibit the largest departures from the low mortality benchmark and higher inequality. However, results for females are shown in the Additional file 1.

Figure 2 shows trends in inequalities between states in Mexico for males in the three age groups, as measured by the coefficient of variation (results for females are reported in Additional file 1, Figure 2). This indicator measures the variation in the gap of temporary life expectancy with the low mortality benchmark between states within the three age groups. Larger values are related to higher disparities between states. Trends show mixed patterns of convergence with temporary divergence, and with females in all cases showing less between-state inequality than males over the entire period studied.

There are important differences in inequality levels and trends between age groups. Since 1990, state inequality in life expectancy in the youngest age group has been decreasing. Among females, young adults show even lower values than the population in the youngest age group. However, for males in the young adult age-group a crossover in the early 2000's is seen, with the coefficient of variation increasing after 2005. The highest values are observed in the period 2009-2011. By 2015, state inequalities among young adults had decreased substantially, but still remain higher than that of the youngest age group. Older adults show substantially higher inequality than the other age groups over the entire period studied, but also show steady convergence between states. From 2013, both males and females show a potential rise in disparities between states, although could be random variation since it only accounts for 2 years (Additional file 1 Figure 2).

[Figure 2 about here]

To illustrate discordance between age groups within each state, Figure 3 shows the state ranking of temporary life expectancy for the years 2010-15 for males in each age group (see Additional file 1, Figure 3 for females' results). States at the top show the highest values in temporary life expectancy, while states in the bottom refer to the lowest values. We chose to highlight the states with most discordant age-rankings. Green and purple lines refer to selected states that show drastic changes in the ranking between different age groups. For example, Sinaloa, in the northern part of Mexico, holds the record life expectancy below age 15; however, young adults (15-49) show one of the lowest values, while older adults are in the sixth position out of 32. Similar trajectories are shown with green lines for Nayarit and Michoacán in the central region, Zacatecas in the North, as well as Morelos and Guerrero from the southern region. Conversely, the pattern of age discordance in Hidalgo, Querétaro and Mexico City from the central region, and Yucatan and Puebla in the South (purple lines) is summarized by changing from a low rank in the youngest age group to a high rank in young adults, followed by low rank in older adults.

We performed a two-way ANOVA on temporary life expectancy by state and age-groups controlling for year. There was a statistically significant interaction between the effects of states and age groups [$F=12.25$, $p < .001$] indicating, as shown in Figure 3, that part of the existing variation in the country is due to within-variability in each state. There were also significant differences in temporary life expectancy between age groups [$p < .001$] and states [$p < .001$] reflecting between-state variability, as shown in Figure 2.

[Figure 3 about here]

Cause-decomposition analysis

In Figures 4 and 5, the Mexican states in each region are arranged according to the largest gap with the low mortality benchmark among older adult males in 2015. Figure 4 shows how causes amenable to medical service, diabetes, ischemic heart diseases (IHD), lung cancer, cirrhosis, homicide, and road traffic accidents contributed to the gap between each state and the low mortality benchmark from 1990 to 2015 for male older adults (ages 50-84). These are the causes of death that contributed the most to holding states back from achieving the low mortality benchmark. Light-yellow colors indicate negligible contributions, which means that are very close to the low mortality benchmark within each category. Darker red hues indicate larger contributions to the gap. If a particular state is improving during the period, it shows a transition from red to light-yellow.

Medically amenable causes of death show gradual improvements in most states from 1990 to 2015, bringing them closer to the benchmark in this category. However, large disparities between states and potential for improvements remain. For example, Baja California, Sonora, Chihuahua and Coahuila from the northern region show substantial contributions to the gap. Diabetes mortality has increasingly contributed to widening the benchmark gap in several states, including Coahuila and Tamaulipas in the North, Mexico City, Guanajuato, Mexico state and Tlaxcala in the central region, and Puebla, Veracruz and Tabasco in the South. Similarly, IHD significantly affects the northern part of the country, while cirrhosis is mostly concentrated in the South. Lung cancer and road traffic accidents have lower contributions to the benchmark gap, but these remain important causes of death. Homicides increased the gap in this age group in some states after 2005, such as Chihuahua, Durango and Sinaloa in the North, Colima, Michoacán and Nayarit in the central region, and Guerrero in the South.

[Figure 4 about here]

Females show similar regional patterns to males, albeit of lower magnitude. For males, causes amenable to medical service, diabetes, and IHD contributed the largest share to the gap with the low mortality benchmark among older adult females. In the youngest age group, improvements in life expectancy and in reducing the gap with the low mortality benchmark were mainly driven by causes amenable to medical service among both females and males. Finally, homicide mortality and road traffic accidents are the main drivers of the gap with the benchmark among young male adults (ages 15-49). Importantly, homicides contributed more than 2.5 years to the gap with the low mortality benchmark in 2010 in the northern state of Chihuahua, and several states from the North and South of Mexico showed substantial impacts from homicide after 2005. Results for all age-groups are shown in Additional file 1, Figures 4-9.

Potential gains and causes of death in 2015

Figure 5 breaks down the state-specific low mortality benchmark gap for males aged 50-84 into potential gains and their cause of death composition. The left panel shows the potential gains for older adults if the low mortality benchmark were achieved for each state in 2015. The right panel shows the proportion of potential gains due to specific causes of death in the same year.

Every state in Mexico could increase survival by at least one year in older adult ages if they were to achieve the low mortality benchmark. However, for 17 of them the gap with the benchmark is higher than 2 years, and for 3 states in the northern region it is greater than 3 years. For females, with the exception of Sinaloa and Nayarit, all the states show the potential to gain over an additional year of life between ages 50-84.

More than half of these potential gains in life expectancy between ages 50 and 84 are due to medically amenable causes, diabetes, IHD, and cirrhosis in every state in Mexico (right panel). This is true also for females. Although older males show lower impact of homicide mortality on potential gains compared to young adult males (15-49), its effect is present in almost every state, particularly in Guerrero, Morelos in the South, Nayarit and Colima in the central region, and Sinaloa in the North. Results for all the age groups for the years 2005, 2010, and 2015 are shown in the Additional file 1, Figures 10-18.

[Figure 5 about here]

Discussion

In Mexico since 1990, life expectancy in three large age groups has followed discordant patterns of rise, stagnation, and deterioration. Such patterns have been driven mainly by causes of death that are amenable to medical service (such as infectious and respiratory diseases) and health behaviors (such as homicides, diabetes, IHD, and cirrhosis) as subcategories of the broader concept of Avoidable/Amenable mortality (AM). Patterns in these two large cause-of-death categories led to contrasting levels of inequality in the country.

Life expectancy below age 15 converged towards the low mortality benchmark and maximum survival in all 32 Mexican states. These results underscore public health interventions aimed at youngest ages. This is supported by evidence that vaccination coverage has been achieved for the entire young population, and that health insurance coverage has improved, due to vaccination programs and the implementation of *Seguro Popular* along with previous established health systems, respectively.[9] Causes amenable to medical service are at the heart of such improvements, consisting of decreases in infectious and respiratory diseases associated with public health interventions targeting children.[6] For example, Puebla and Tlaxcala (in the South and central regions respectively) were the states with the lowest life expectancy below age 15 in 1990 and have improved by more than half a year since then. Moreover, the average over states improved from 14.5 in 1990 to 14.8 in 2015, with no state below 14.7. As a result of continuous and nationwide convergence towards the low mortality benchmark, inequalities between states in life expectancy below age 15 have been reduced.

Opposing the optimistic trend in the under-15 population, increases in homicide mortality reversed gains in male life expectancy, particularly between ages 15-49. These results are consistent with previous studies quantifying the effect of homicide mortality on the stagnation of national life expectancy at birth in the first decade of the 21st century,[3] and with the reversal experienced in life expectancy in most states between 2005 and 2010.[14] Our results extend such findings by adding five years of data and segmenting by specific age groups. We found that after ten years of the unexpected rise in homicide mortality, most states have experienced a slow and partial recovery since 2010. However, the impact of homicide is still higher than the levels observed in 2005. Between 2010 and 2015, this cause of death accounted for most of the gap between states and the low mortality benchmark in ages 15-49. For this age group, the states that show the greatest benchmark gap for homicide in 2015 are Guerrero in the South, and Sinaloa and Chihuahua in the North, which could gain one year, and half a year (each) respectively if homicides were reduced to the level of the southern state of Yucatán, which in this case makes up 100% of the benchmark. Moreover, health inequalities in life expectancy between states followed the rise in homicides after 2005 (Figure 2), and the considerable discordance between age-groups (Figure 3) was likely due in great part to homicide mortality in ages 15-49. It is unclear how these levels of state life expectancy will change with the new reports which highlight a three year increase in homicide in Mexico.[22,ii]

The population aged 50-84 shows the largest low mortality benchmark gap in both females and males. Out of 35 livable years in this age group, females lived on average 28.6 years and males 26.5 in 2015 without any clear improvement in the 26 years since 1990. Even the low mortality benchmark itself shows a downward trend for males and females (Figure 1). Moreover, this age group exhibits the highest inequality between states in the last 26 years. Our results show that causes of death holding states back from the low mortality benchmark vary between regions. Causes amenable to medical service showed gradual improvements in almost every state since 1990. However, in some states of the northern region such as Baja California, Sonora, and Chihuahua, these causes of death still show large room for improvements among older adults. Diabetes, Ischemic Heart Diseases (IHD) and cirrhosis account for the majority of the gap with the benchmark mortality with large regional differences. For example, IHD is mostly concentrated in the North (Figure 4), while cirrhosis and diabetes show a stronger impact in the central and southern regions. These results are supported by previous evidence documenting an increase in adult mortality rates from chronic kidney disease, diabetes, and cirrhosis since 2000.[20] Lung cancer and homicides had a lower impact on life expectancy for this age group, and both are higher in the northern part of the country.

Strengths and limitations of the study

The methodology we performed enables to measure the impact of medically amenable mortality and behavior-related mortality on life expectancy relative to a low mortality benchmark in three large age groups. It allows to analyze patterns in life expectancy for different age groups over time and simultaneously account for changes in causes of death and inequality between populations that have undergone major social and public health transitions. Therefore, it is imperative to consider the effect of different causes of death to estimate the effectiveness of public health and policy interventions.

The limitations of our study should be mentioned. First, Mortality data from Mexico are likely to present inaccuracies in cause-of-death classification due to comorbidities, particularly at older ages.[32] To mitigate this, we focus on ages below 85 and broad groups of causes of death. In addition, road traffic accidents and homicides may happen not in the place of residence but in another state, which might cause differences in state specific mortality. Moreover, our estimates regarding homicide mortality are likely to be underestimated due to inaccurate practices regarding counting, reporting, and due to the large number of missing individuals in Mexico.[33 34] Similarly, in 1997 a change in diagnosis criterion for diabetes took place, and this could have an impact on trends of mortality caused by diabetes in years adjacent to 1997.[35]

Avoidable mortality should be understood as an indicator of potential weaknesses with respect to health care and some public health policies and not as a definitive assessment.[10] The amount of deaths that should be considered within the avoidable classification is not clear [36]. For instance, some researchers consider only 50 percent of heart disease mortality to be avoidable.[37 38] There is no direct information to precisely measure percentages of avoidable mortality within cause groups in Mexico. Nonetheless, the difference between a given mortality schedule and the best mortality schedule of the same year can be conceived of as a minimal definition of avoidable mortality. The benchmark mortality schedule sets a lower bound to how much mortality could have been avoided. Certainly, even the best mortality schedule will contain elements of mortality that most would consider avoidable. To the extent that the components of the benchmark schedule were indeed attained somewhere in Mexico, one can view any excess mortality with respect to the benchmark schedule as avoidable. We believe this perspective improves on the AM concept by giving a directly measurable standard against which to estimate avoidable deaths.

Implications of findings

Beyond the mortality implications of the rise in homicide, violence has had a toll on perceived vulnerability in the country.[39] The recent increase in homicides in some states could trigger an increase in the perception of vulnerability, which would result in a higher average lifetime fear in specific states. Although we are not able to link the trends in mortality among young adults in Mexico with specific public policies, some evidence suggests that the propagation of homicide mortality is not only a result of the war between drug cartels, but also because of the implementation of specific policies aimed to mitigate drug cartel operations after 2006.[40] There is no simple way to lessen the impact of homicide mortality, but it is clear that the government has not been able to reduce its burden back to levels observed before 2005. Furthermore, state homicide rates may underestimate the effect of violence in particular localities. For example, Guerrero in the South, has two of the most dangerous cities in the world,[iii] but no information is available on the heterogeneity in homicide mortality for the rest of the state.

The fact that in 2015 the older adult population of Mexico could add more than one year of life in every state for males, and in 30 states for females by achieving the benchmark mortality levels, underscores vulnerability in these ages. Public health interventions targeting specific causes of death for this age group according to the epidemiological profile of each state would not only increase life expectancy, but it would also forge a path towards more equality between states in health outcomes. More than 50% of the potential gains in life expectancy between ages 50 and 84 are due to avoidable mortality, and to a large extent mortality related to health behaviors and medically amenable causes. For instance, obesity and overweight, risk factors for diabetes and IHD, have dramatically increased since the 1990s in developing countries because of the consumption of cheap, energy-dense food and reduced physical activities.[41] In this sense, Mexico, along with the USA, has the highest rates of overweight and obesity among all OECD countries[18] and one of the highest in Latin America, along with Chile, El Salvador, Honduras, and Paraguay.[42] However, obesity prevalence is not homogeneous across Mexico. The highest rates of obesity are concentrated in the northern and central regions[18] and in urban areas of the country,[43] which roughly matches our regional pattern of IHD and diabetes mortality.

Conclusion

Mexico stands today at an advanced stage of the epidemiological transition.[20] However this transition was achieved rapidly and the health system is ill-prepared for the burden of non-communicable diseases.[44] The cardiovascular mortality reductions that brought the developed world into advanced levels of life expectancy trends, still are in progress in Mexico. Nevertheless, no single solution is available to reduce behavioral mortality in this country since, as we show, great heterogeneity in mortality levels exist among its states.

Signs of a fragile situation in the health and mortality of the oldest age groups is observed in the decline in the low mortality benchmark used in our analysis. The aging of the population could scale up this situation if timely preventive measures are not put in place. Furthermore, a resurgence of violent deaths [14 19 39] has created a new burden in Mexican society.

As many developing countries, Mexico will have to face these new challenges with a broad strategy. This should include a continuous and adaptable health system ready for the current and future health adversities at the physical, mental and societal levels. Many other institutions will also have to coevolve including importantly the development of an education system that embraces and encourages physical and healthy activities in younger and future generations.

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Data sharing: All data used are publicly available in references 22 and 23. All the study is fully replicable at https://github.com/jmaburto/DecompMex
Transparency: The lead author* affirms that this manuscript is an honest, accurate, and transparent account of the study being reported; that no important aspects of the study have been omitted; and that any discrepancies from the study as planned (and, if relevant, registered) have been explained.
Ethical approval: No ethical approval was needed from the institutions' boards since we work with anonymized aggregated publicly available datasets.

Figures

Figure 1. State-specific life expectancy trends (grey), average (black) and low mortality benchmark (blue) for three age groups, the youngest (0-14), young adults (14-49), and older adults (50-84) by sex for the period 1990-2015. Source: calculations based on INEGI and CONAPO files.

Figure 2. Inequality in male life expectancy between states for the youngest (0-14), young adults (15-49) and older adults (50-84), 1990-2015. Source: calculations based on INEGI and CONAPO files.

Figure 3. Discordant age-rankings for average male life expectancy 2010-15 for the youngest (0-14), young adults (14-49), and older adults (50-84). Source: calculations based on INEGI and CONAPO files.

Figure 4. Cause-specific contributions to the gap between states and low mortality benchmark for older male adults (50-84), 1990-2015. Source: calculations based on INEGI and CONAPO files.

Figure 5. State-specific gap with the low mortality benchmark and its cause-of-death composition for older male adults (50-84) in 2015. Source: calculations based on INEGI and CONAPO files.

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Endnotes

[i] The percentage of the population aged 65 or older is projected to go from 6.0% in 2015 to 10.2% in 2030 (Reference: CONAPO)

[ii] [https://www.businessinsider.com.au/homicides-hit-new-high-mexico-alongside-increase-in-robberies-2017-11?r=US&IR=T]

[iii] [http://www.economist.com/blogs/graphicdetail/2017/03/daily-chart-23]

Additional Files

Additional fille 1 | Supplemental material

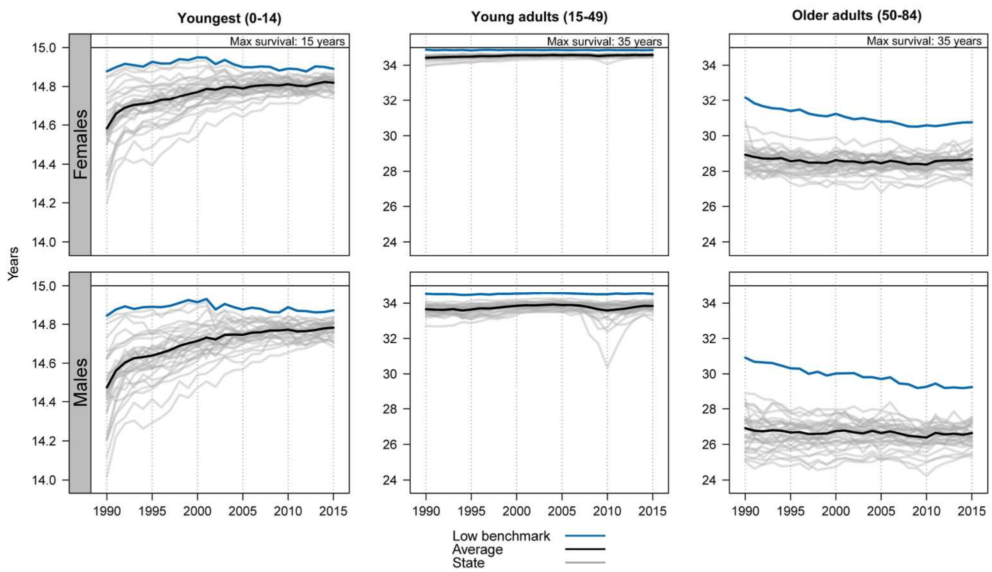

Figure 1. State-specific life expectancy trends (grey), average (black) and low mortality bench-mark (blue) for three age groups, the youngest (0-14), young adults (14-49), and older adults (50-84) by sex for the period 1990-2015. Source: calculations based on INEGI and CONAPO files.

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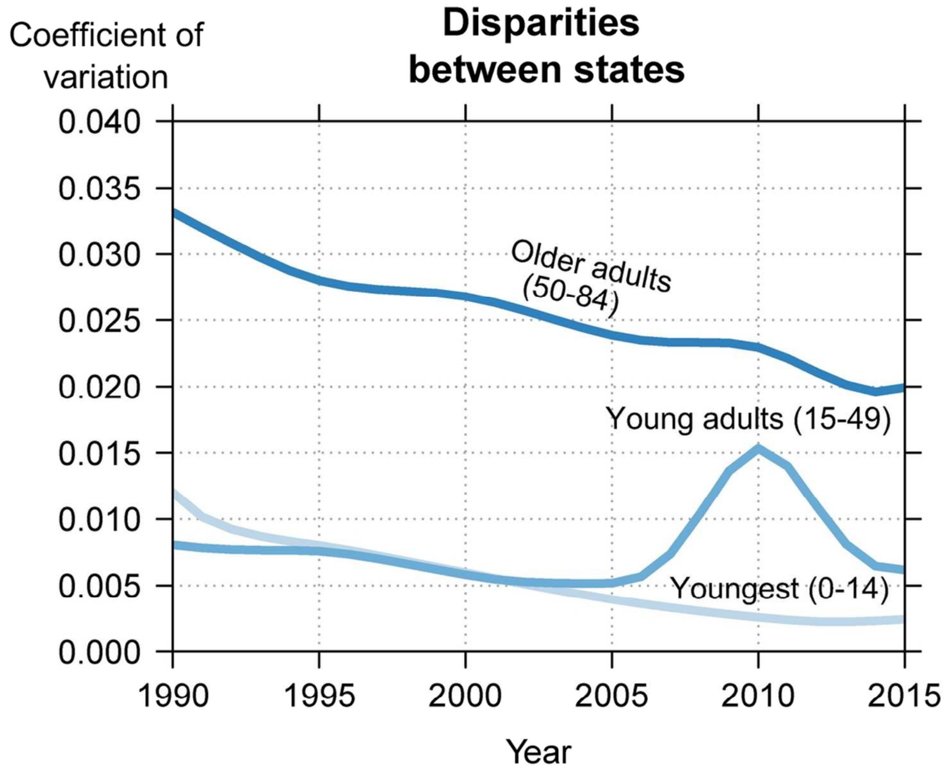

Figure 2. Inequality in male life expectancy between states for the youngest (0-14), young adults (15-49) and older adults (50-84), 1990-2015. Source: calculations based on INEGI and CONAPO files.

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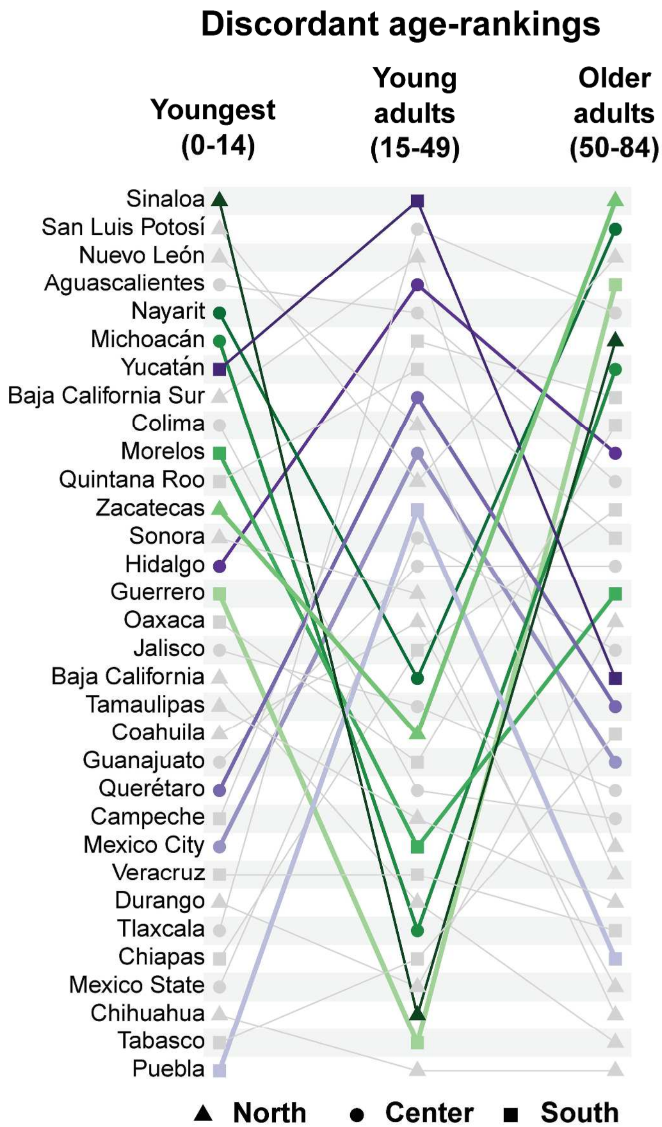

Figure 3. Discordant age-rankings for average male life expectancy 2010-15 for the youngest (0-14), young adults (14-49), and older adults (50-84). Source: calculations based on INEGI and CONAPO files.

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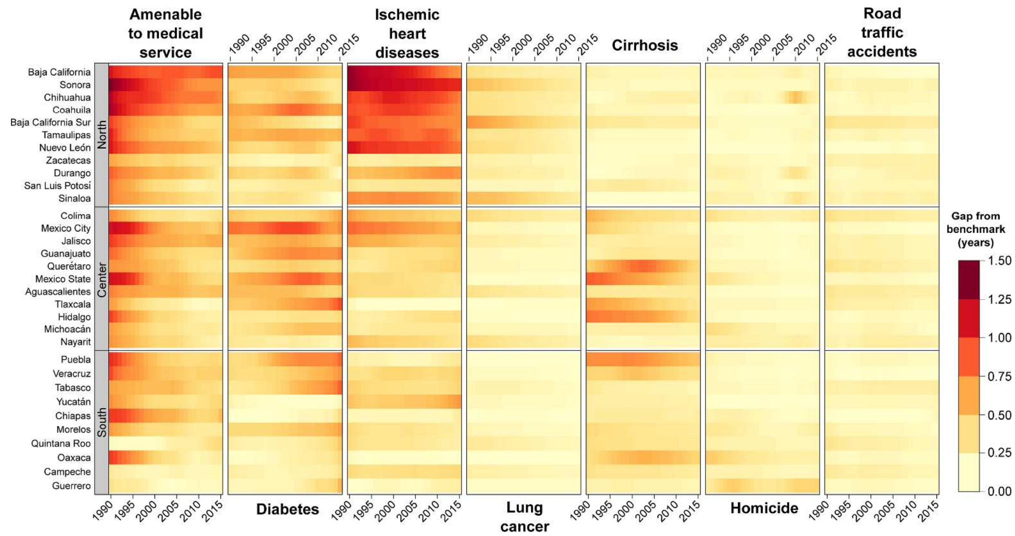

Figure 4. Cause-specific contributions to the gap between states and low mortality benchmark for older male adults (50-84), 1990-2015. Source: calculations based on INEGI and CONAPO files.

268x140mm (300 x 300 DPI)

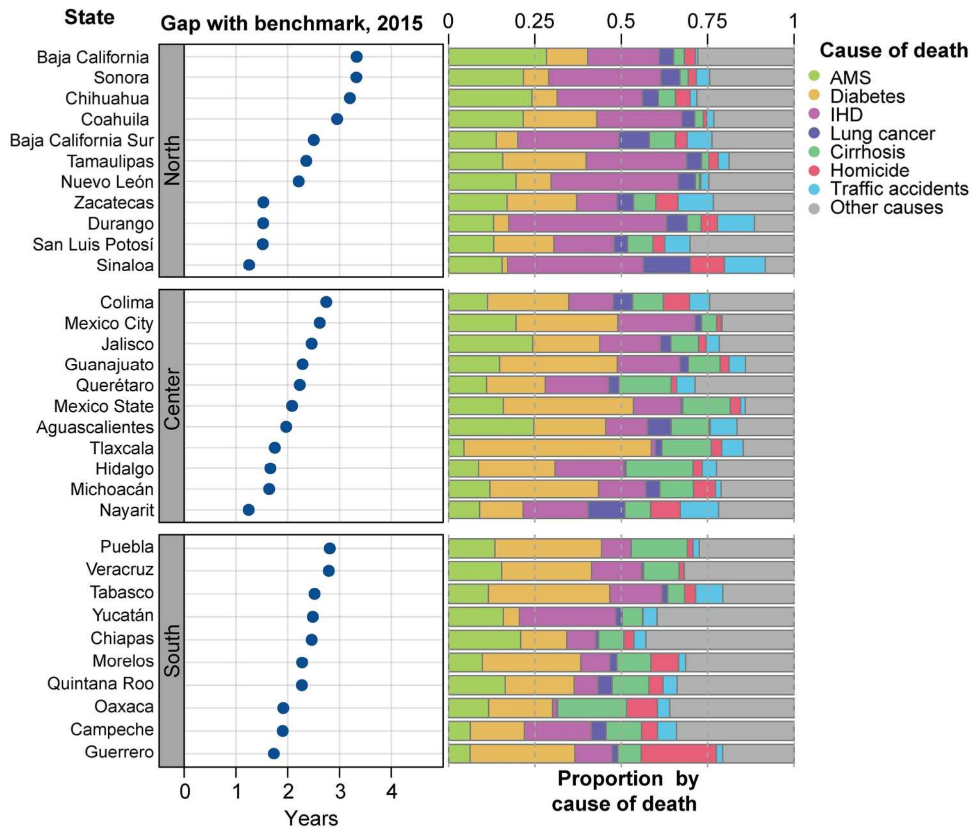

Figure 5. State-specific gap with the low mortality benchmark and its cause-of-death composi-tion for older male adults (50-84) in 2015. Source: calculations based on INEGI and CONAPO files.

177x155mm (300 x 300 DPI)

Inequalities in life expectancies among Mexican states, 1990-2015: deterioration in adult survival

José Manuel Aburto[1], Tim Riffe[2], and Vladimir Canudas-Romo[3]

[1]Institute of Public Health, University of Southern Denmark
[2]Max Planck Institute for Demographic Research
[3]School of Demography, Australian National University

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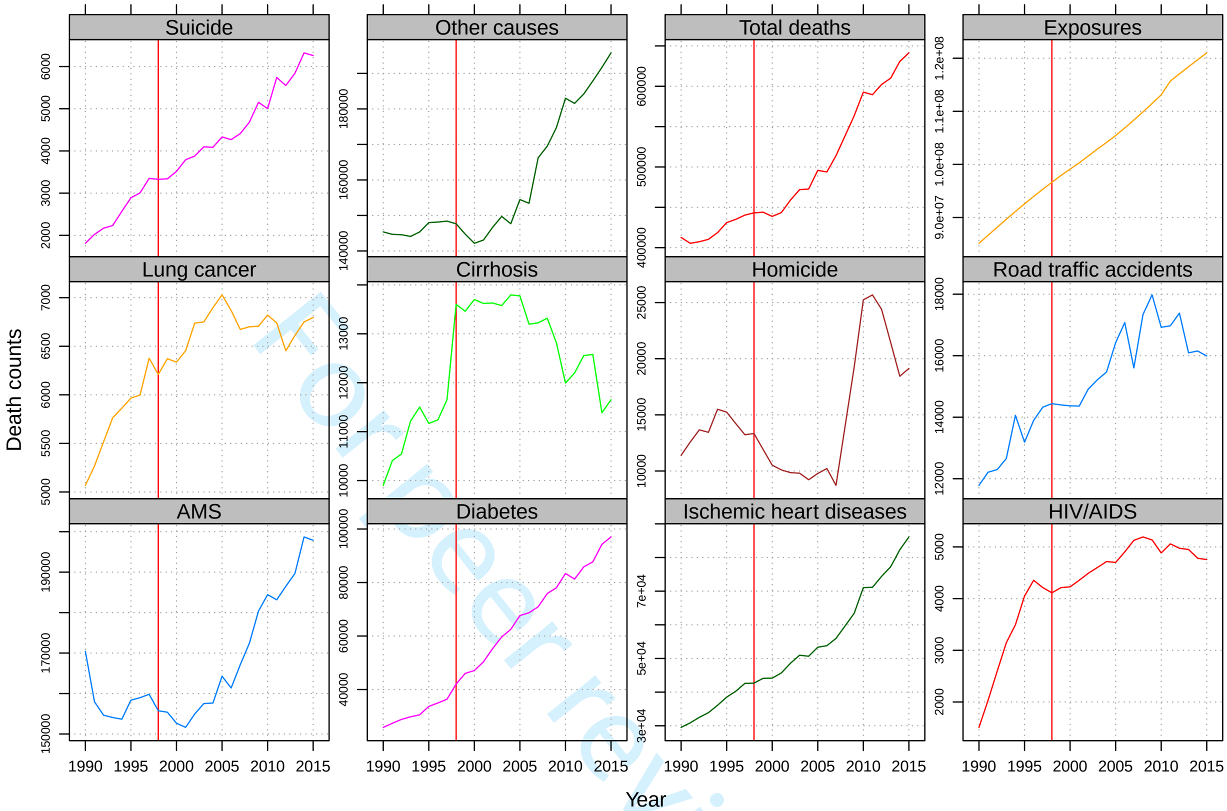
Supplemental material

Appendix Table 1. Definitions of cause-of-death categories using the 9th and 10th revision of the International Classification of Diseases.

Category	ICD-10	ICD-9
I. Amenable to medical service		
I.A. AM-Infectious & respiratory diseases : intestinal infections, tuberculosis, zoonotic bacterial diseases, other bacterial diseases, septicemia, poliomyelitis, measles, rubella, infectious hepatitis, ornithosis, rickettsioses/ arthropod-borne, syphilis (all forms), yaws, respiratory diseases, influenza & pneumonia, chronic lower respiratory diseases	A00-A09, A16-A19, B90, A20-A26, A28, A32, A33, A35, A36, A37, A40-A41, A80, B05-B06, B15-B19, A70, A68, A75, A77, A50-A64, A66, J00-J08, J20-J39, J60-J99, J09-J18, J40-J47	001-009, 010-018, 32, 33, 37, 137, 020-027, 38, 45, 55-56, 70, 73, 080-082, 087, 090-099, 102, 460-479, 500-519, 480-488, 490-496
I.B. AM-Cancers: malignant neoplasm of colon, skin, breast, cervix, prostate, testis, bladder, kidney-Wilm's tumor only, eye, thyroid carcinoma, Hodgkins disease, leukemia	C16,C18-C21, C43-C44, C50, C53, C61, C62, C67, C64, C69, C73, C81, C91-C95	153-154, 172-173, 174, 180, 185, 186, 188-189, 190, 193, 201, 204-208
I.C. AM-Circulatory: active/acute rheumatic fever, chronic rheumatic heart disease, hypertensive disease, cerebrovascular disease	I00-I02, I05-I09, I10-I13, I15, I60-I69	390-392, 393-398, 401-405, 430-438
I.D. AM-Birth: maternal deaths (all), congenital cardiovascular anomalies, perinatal deaths (excluding stillbirths)	O00-O99, Q20-Q28, P00-P96	630-676, 745-747, 760-779
I.E. AM-Other: disease of thyroid, epilepsy, peptic ulcer, appendicitis, abdominal hernia, cholelithiasis & cholecystitis, nephritis, benign prostatic hyperplasia, misadventures to patients during surgical or medical care, cisticerchosis	E00-E07, 40-G41, K25-K27, K35-K38, K40-K46, K80-K81, N00-N07, N17-N19, N25-N27, N40, Y60-Y69, Y83-Y84, B69	240-246, 345, 531-533, 540-543, 550-553, 574-575.1, 580-589, 600, E870-E876, E878-E879
II. Diabetes	E10-E14	250
III. Ischemic Heart Diseases (IHD)	I20-I25	410-414, 429.2
IV. Lung cancer	C33-C34	162
V. Cirrhosis	K70	571.1-571.3
VI. Homicides	X85-Y09	E960-E969
VII. Road traffic accidents	V01-V99	E810-E819
VIII. Residual Causes : HIV/AIDS; suicide and self-inflicted injuries; other cancers and other heart diseases	B20-B24, U03; X60-X84, Y87.0; C00-D48; I00-I99 if not listed above; R00-R99	042-044; E950-E959; 140-239; 390-459 if not listed above; 780-799

Figure 1: Cause-specific death counts (different y-scale for each cause), 1990-2010.



Note: AMS "amenable to medical service". The red line indicates the change from ICD 9 to ICD 10.

Temporary Life Expectancy

Temporary life expectancy between ages x_1 and x_2, for $x_1 < x_2$, is defined as the average years of life lived between these ages according to a given set of mortality rates (Arriaga 1984). We denote this quantity as ${}_{(x_2-x_1)}e_{x_1}$, and its benchmark based on minimum death rates for every age and cause of death among the Mexican states for each year as ${}_{(x_2-x_1)}e^{\star}_{x_1}$. Defined in terms of the lifetable survival function, $\ell(x)$:

$$ {}_{(x_2-x_1)}e_{x_1} = \frac{\int_{x_1}^{x_2} \ell(x)\, \mathrm{d}x}{\ell(x_1)} \tag{1} $$

If full survival is achieved, the life expectancy is $x_2 - x_1$. For example, if we set $x_1 = 0$ and $x_2 = 15$, and no person dies between the ages 0 and 15, on average the population lives 15 full years.

References

Arriaga, E. E. (1984). Measuring and explaining the change in life expectancies. *Demography*, 21(1):83–96.

Figure 2: Inequality in life expectancy between states for youngest (0-14), young adults (15-49), and older adults (50-84) by sex, 1990-2015.

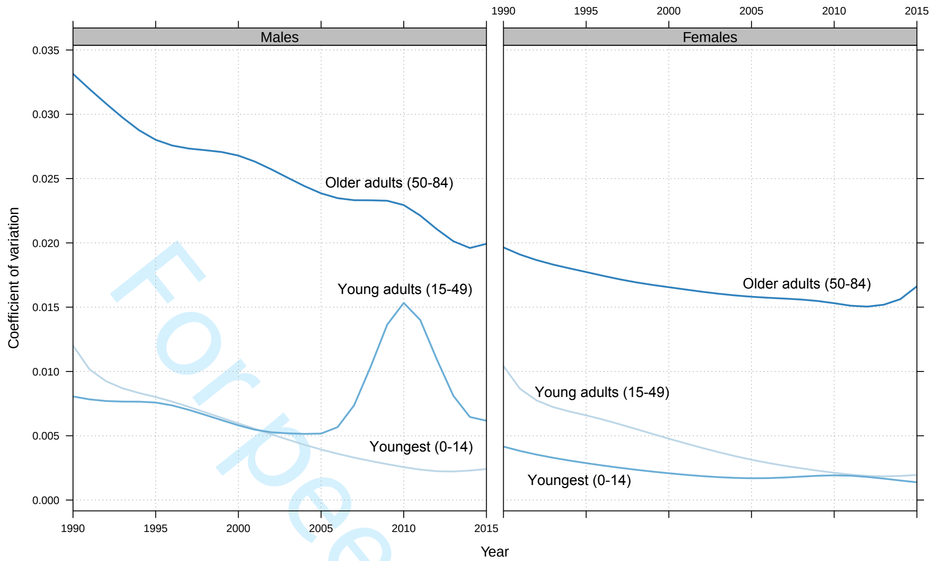
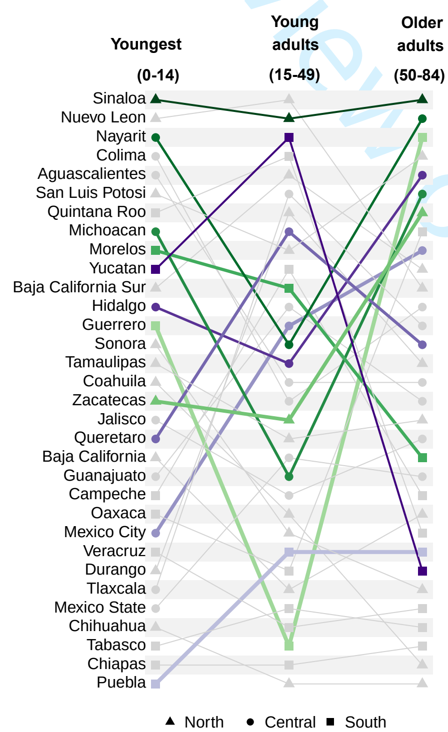
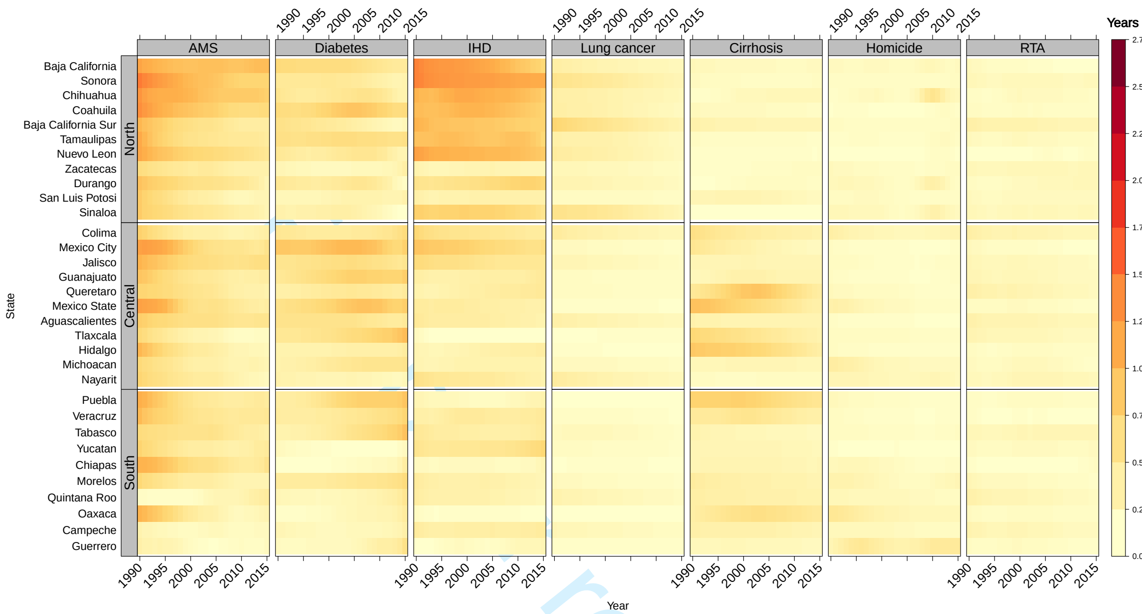


Figure 3: State ranking for average female life expectancy 2010-15 for the youngest (0-14), young adults (15-49), and older adults (50-84).



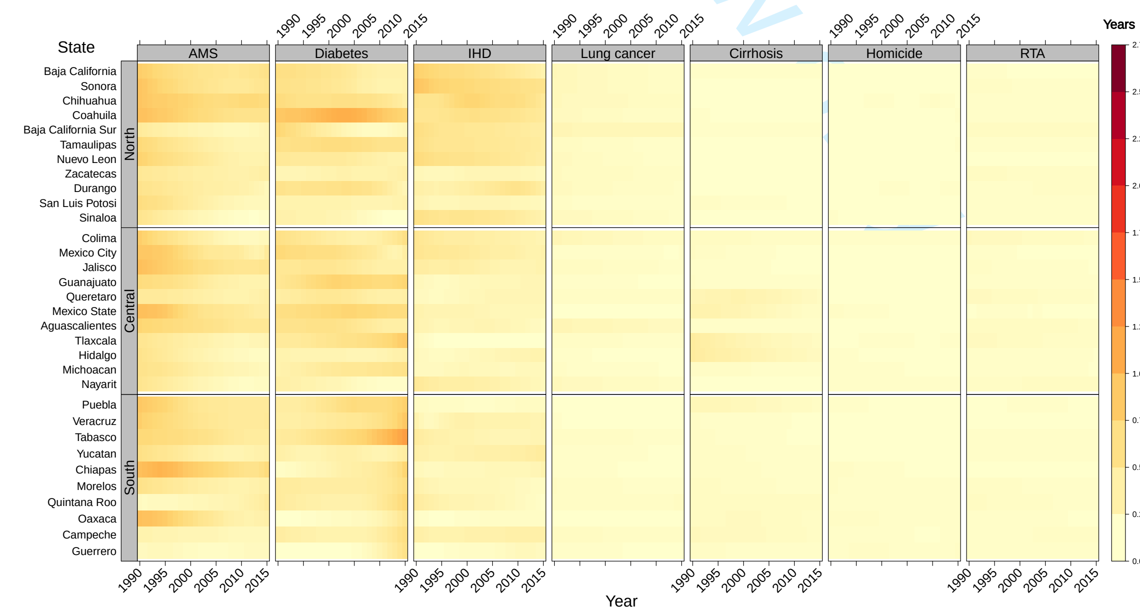
Source: calculations based on INEGI and CONAPO files.

Figure 4: Cause-specific contributions to state differences from low mortality benchmark for older male adults (ages 50-84), 1990-2015. States grouped into three regions. Reproduced from manuscript Figure 4 to have color scale comparable with other Supplementary figures. In subsequent figures 5-9 the color was rescaled to make them comparable over age groups in the supplemental material, the maximum value observed was 2.6 years caused by homicides in Chihuahua in 2010.



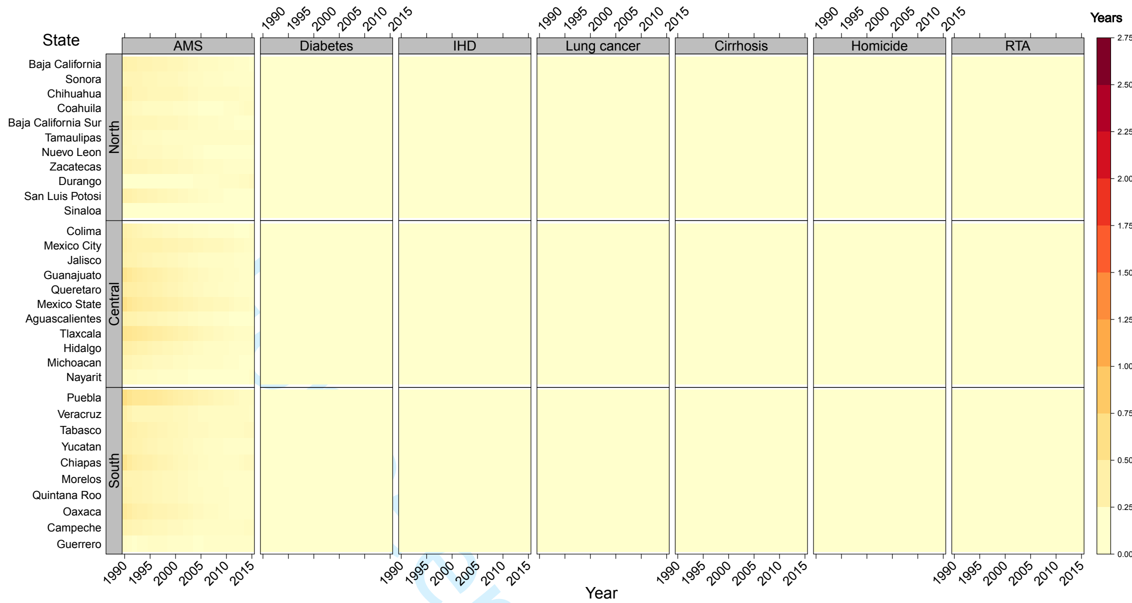
Note: AMS is “amenable to medical service”, IHD is “isquemic heart diseases”, and RTA is “road traffic accidents”. Source: own calculations.

Figure 5: Cause-specific contributions to state differences from low mortality benchmark for older female adults (ages 50-84), 1990-2015.



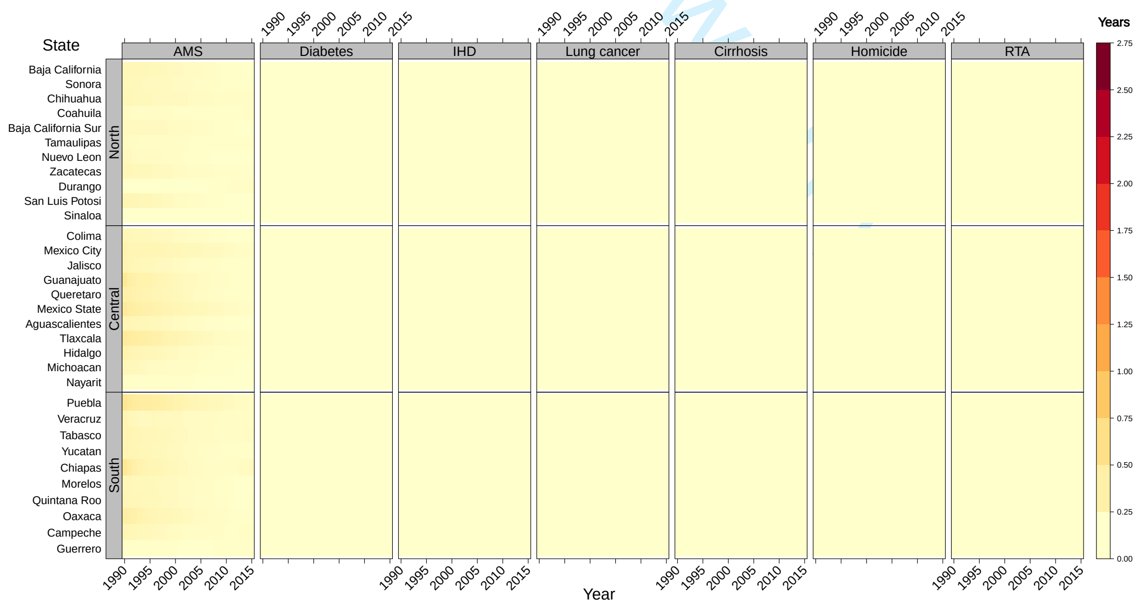
Note: AMS is “amenable to medical service”, IHD is “isquemic heart diseases”, and RTA is “road traffic accidents”. Source: own calculations.

Figure 6: Cause-specific contributions to state differences from low mortality benchmark for male youngest population (ages 0-14), 1990-2015.



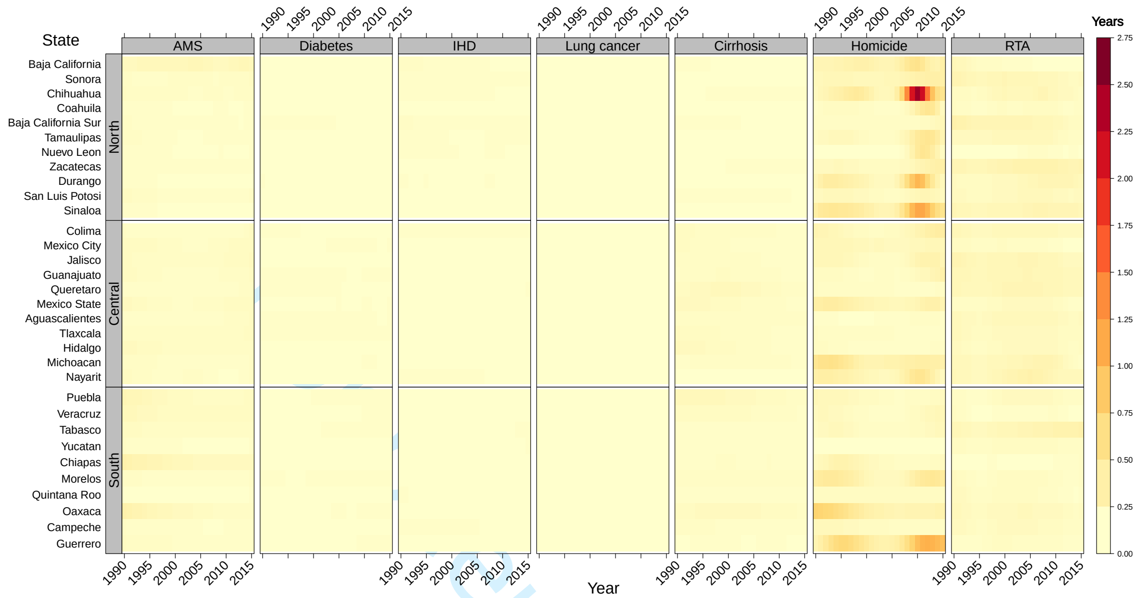
Note: AMS is “amenable to medical service”, IHD is “isquemic heart diseases”, and RTA is “road traffic accidents”. Source: own calculations.

Figure 7: Cause-specific contributions to state differences from low mortality benchmark for female youngest population (ages 0-14), 1990-2015.



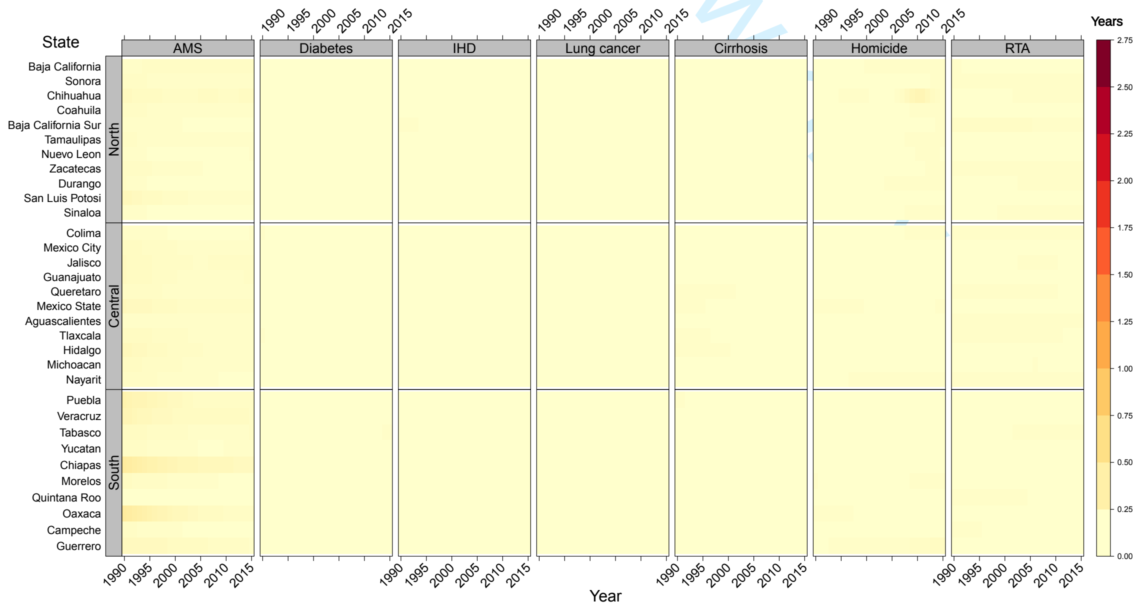
Note: AMS is “amenable to medical service”, IHD is “isquemic heart diseases”, and RTA is “road traffic accidents”. Source: own calculations.

Figure 8: Cause-specific contributions to state differences from low mortality benchmark for male young adults (ages 15-49), 1990-2015.



Note: AMS is "amenable to medical service", IHD is "isquemic heart diseases", and RTA is "road traffic accidents". Source: own calculations.

Figure 9: Cause-specific contributions to state differences from low mortality benchmark for female young adults (ages 15-49), 1990-2015.



Note: AMS is "amenable to medical service", IHD is "isquemic heart diseases", and RTA is "road traffic accidents". Source: own calculations.

Figure 10: State specific gap with low mortality benchmark for selected years between ages 0-14. Source: own calculations.

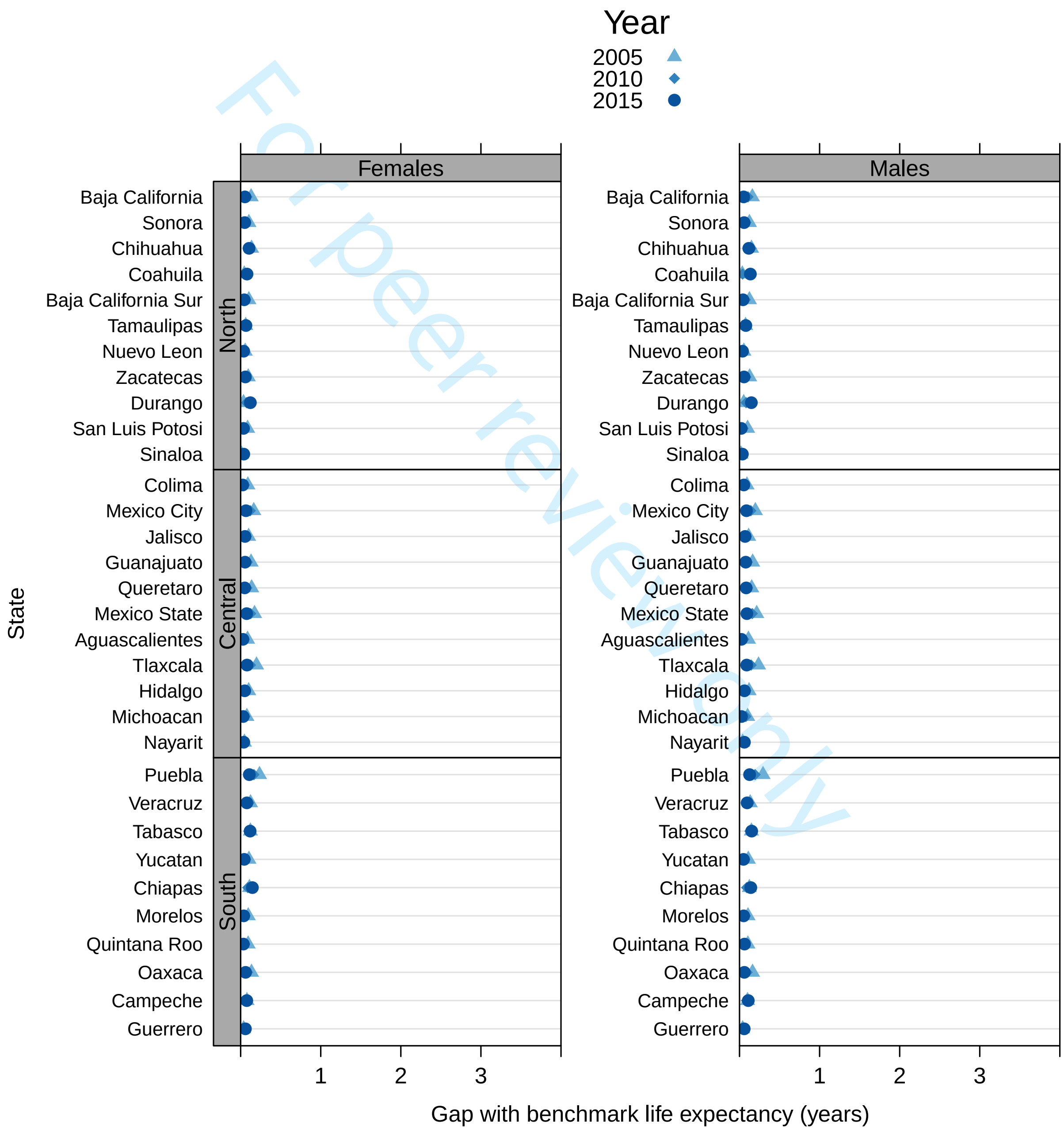


Figure 11: State specific gap with low mortality benchmark for selected years between ages 15-49. Source: own calculations.

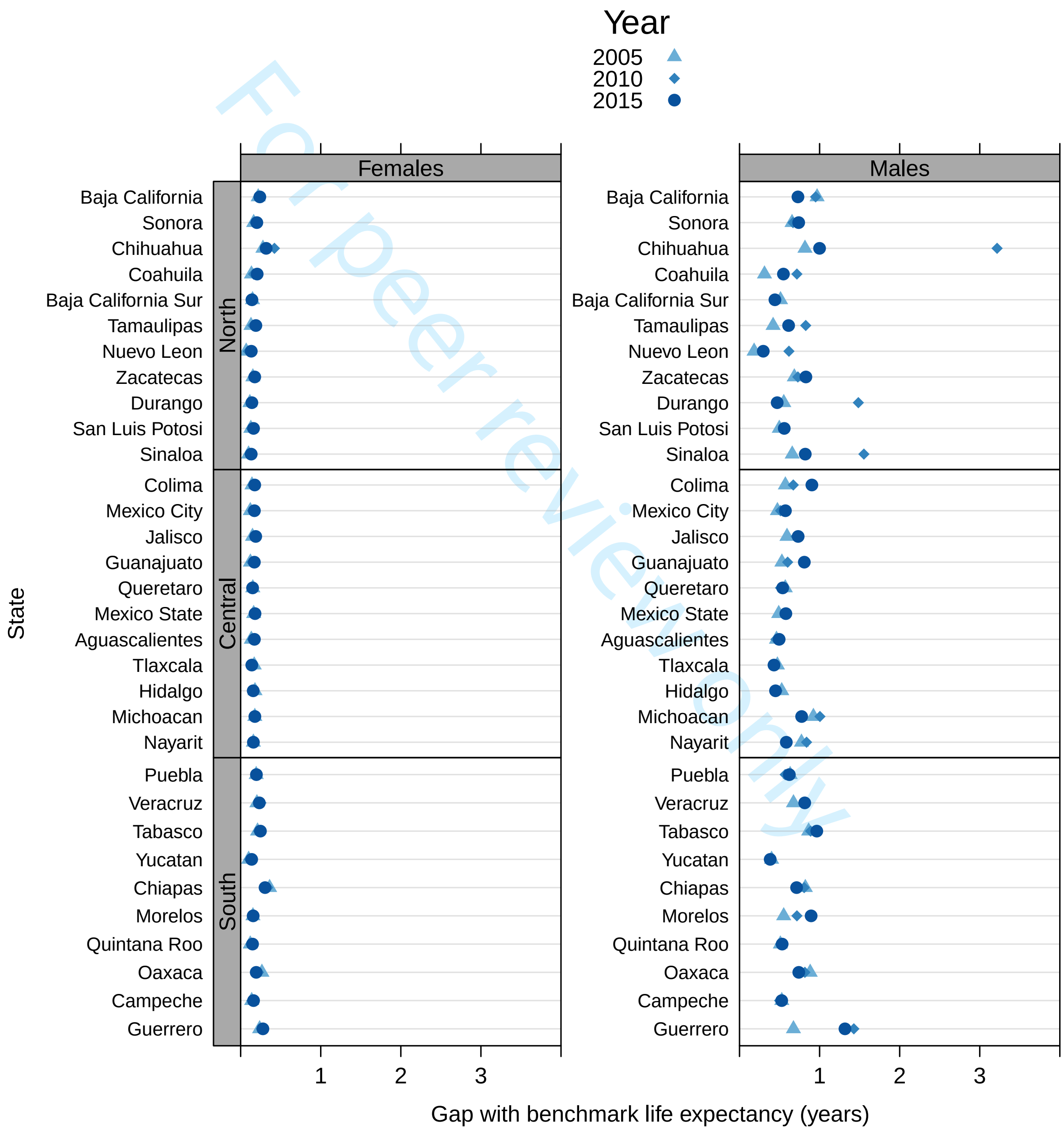


Figure 12: State specific gap with low mortality benchmark for selected years between ages 50-84. Source: own calculations.

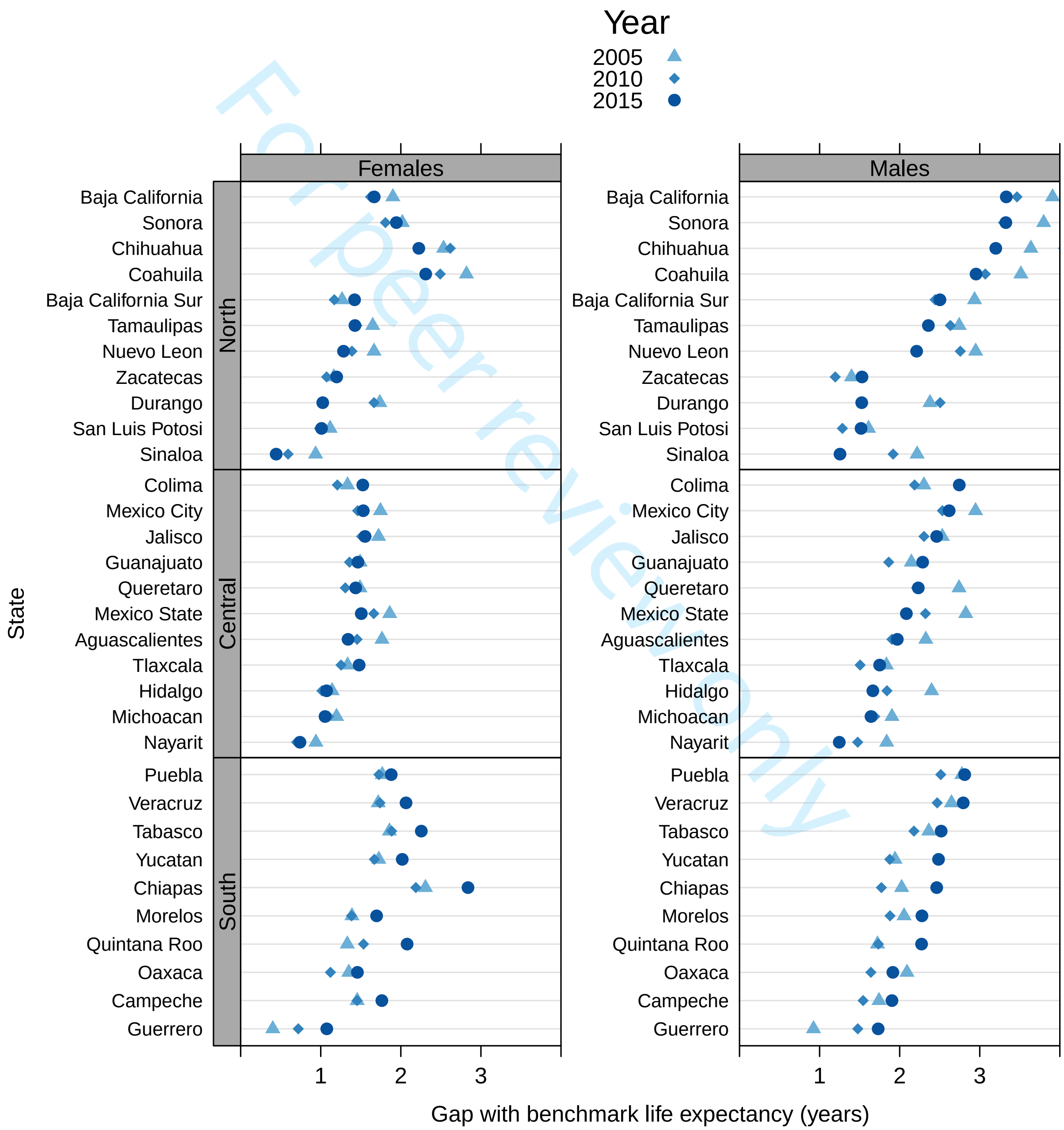


Figure 13: Proportion by cause of death from benchmark mortality for youngest females (ages 0-14). Source: own calculations.

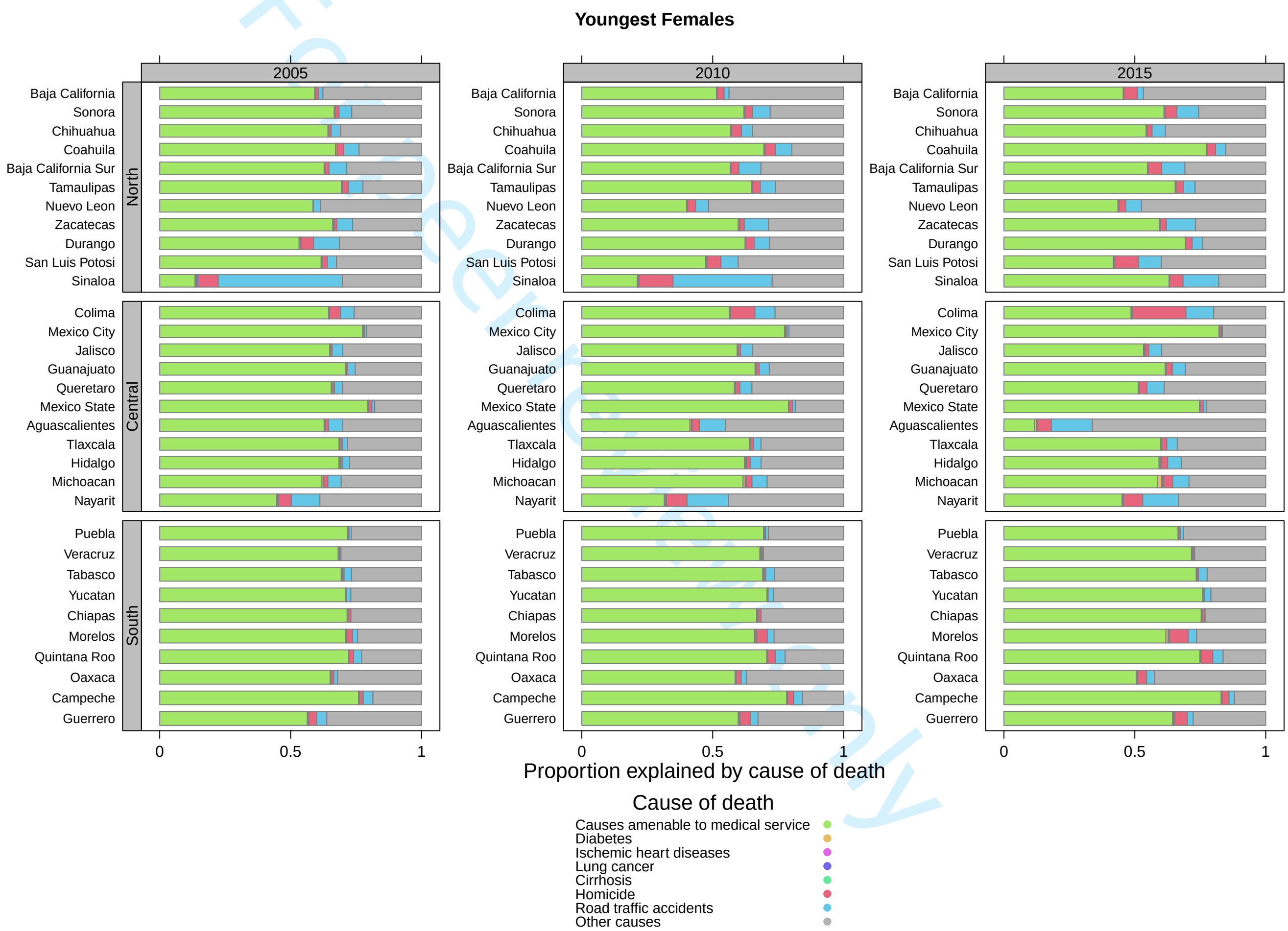


Figure 14: Proportion by cause of death from benchmark mortality for youngest males (ages 0-14). Source: own calculations.

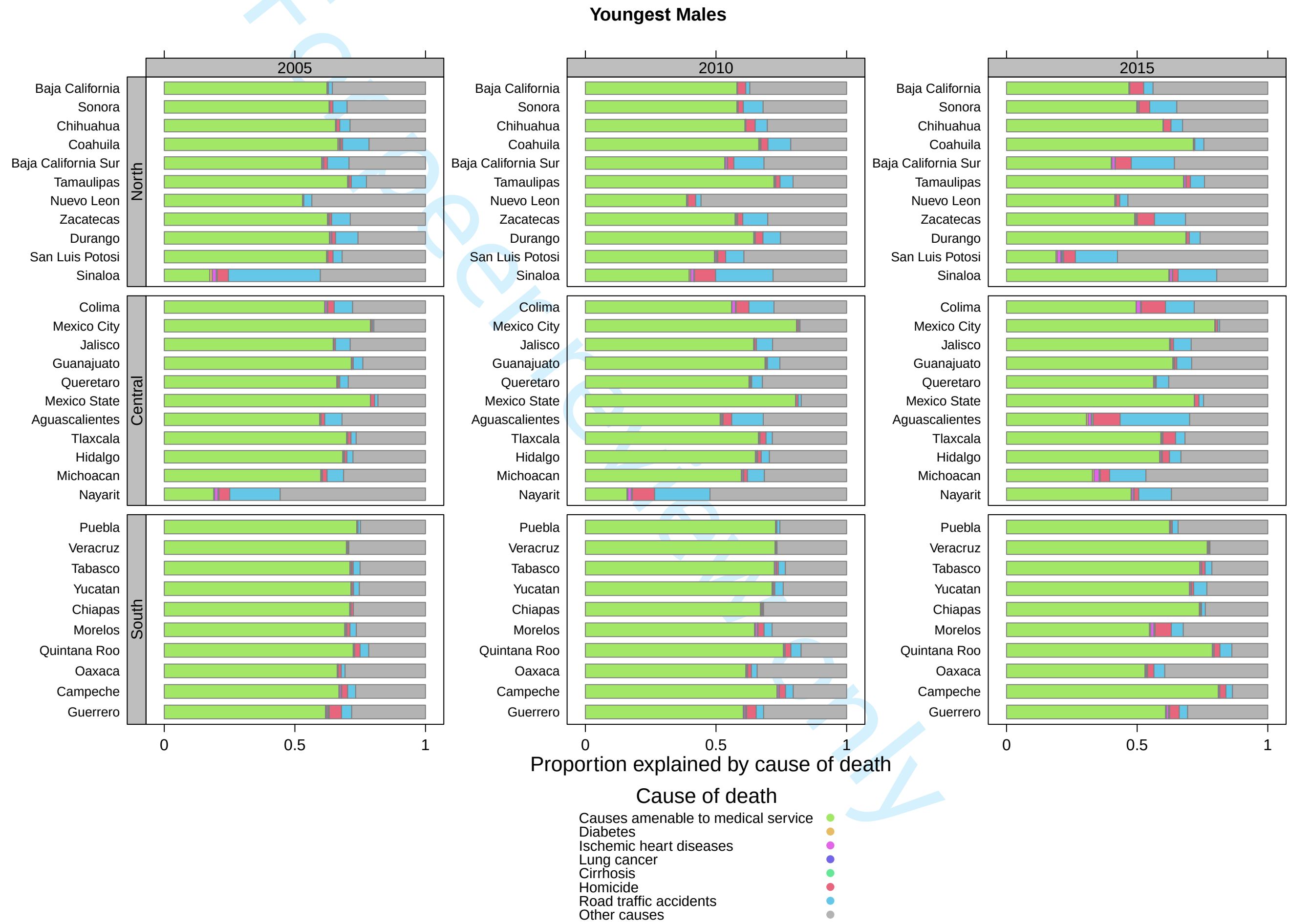


Figure 15: Proportion by cause of death from benchmark mortality for young adult females (ages 15-49). Source: own calculations.

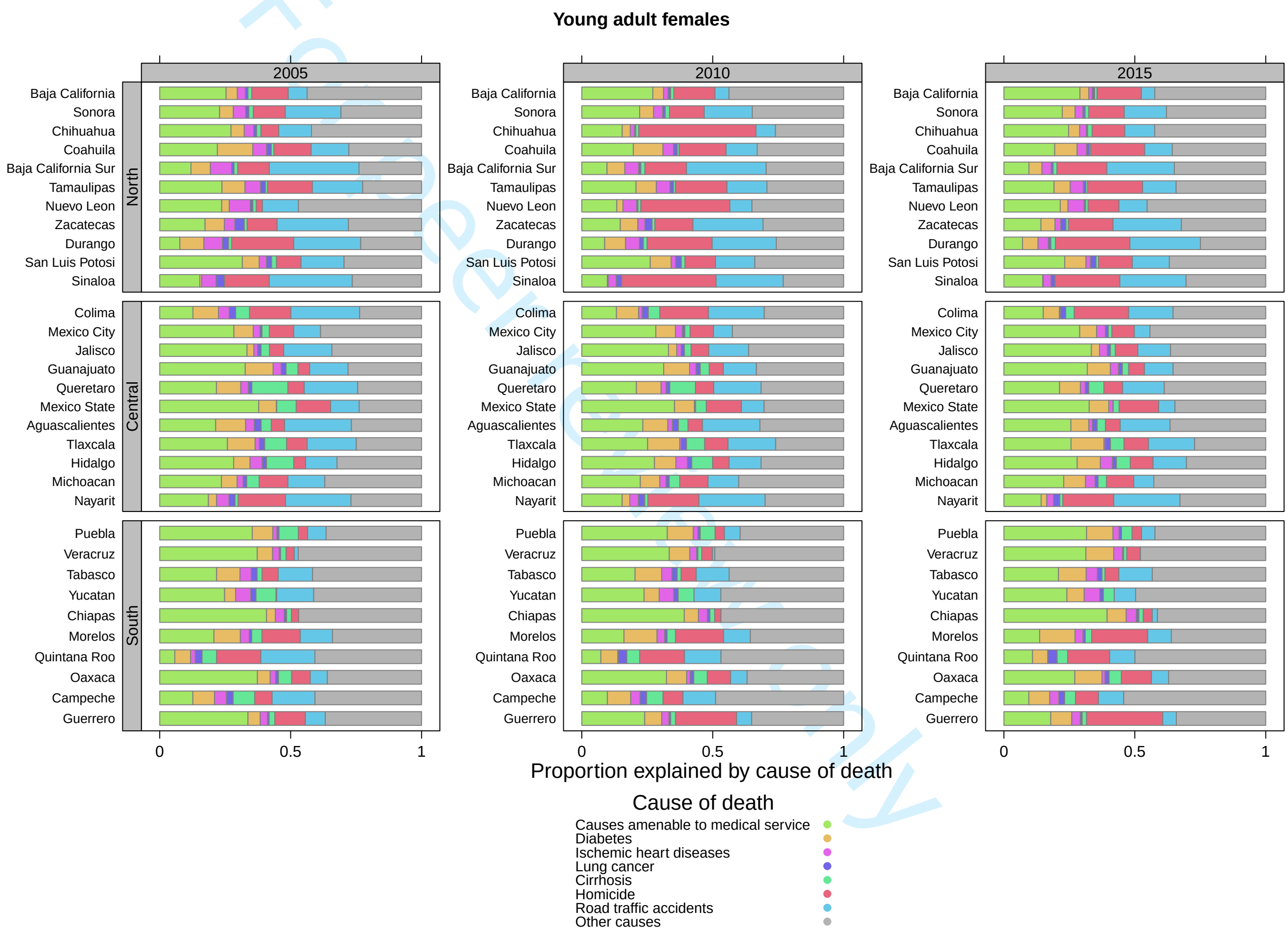


Figure 16: Proportion by cause of death from benchmark mortality for young adult males (ages 15-49). Source: own calculations.

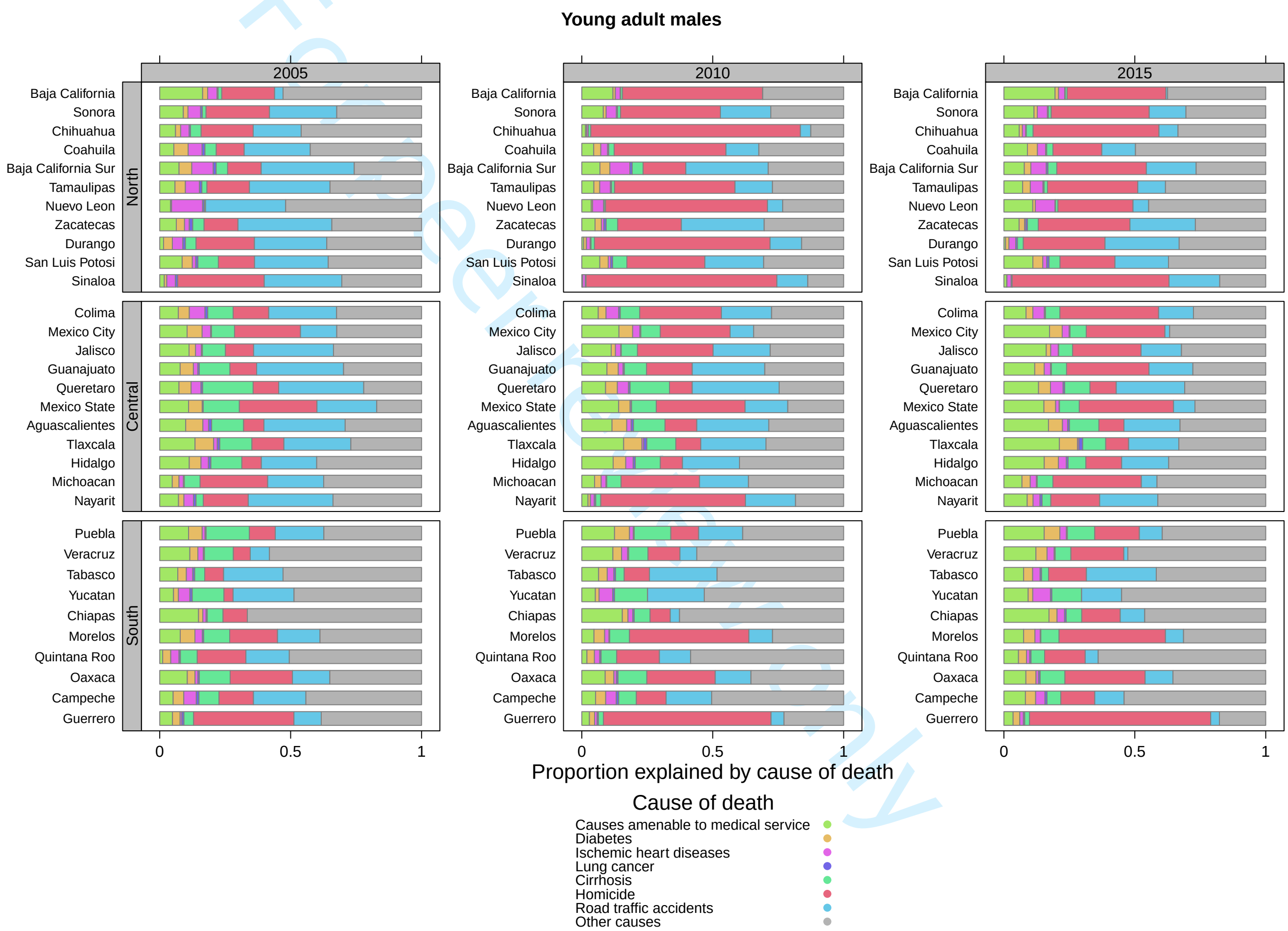


Figure 17: Proportion by cause of death from benchmark mortality for older male adults (ages 50-84). Source: own calculations.

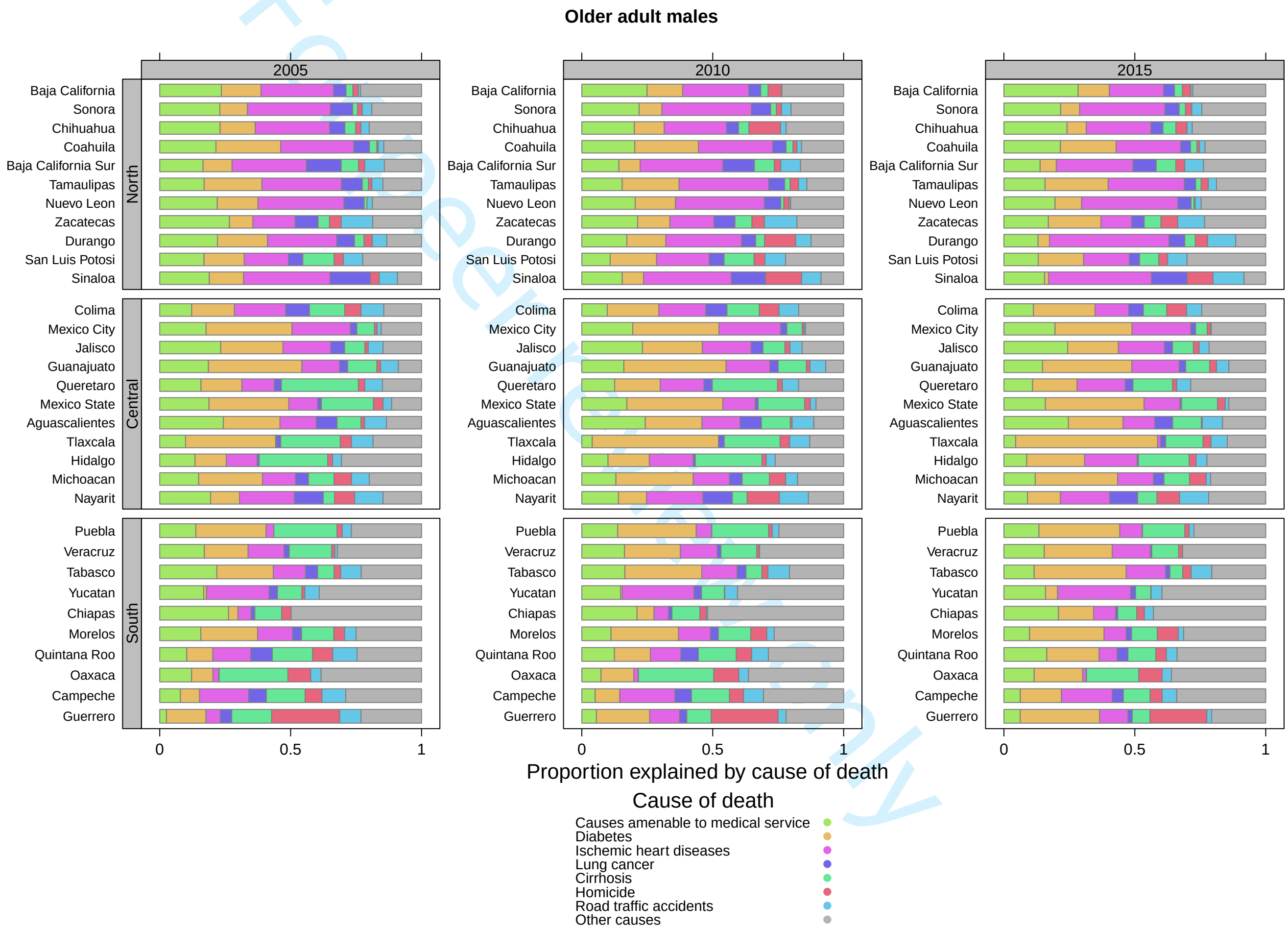
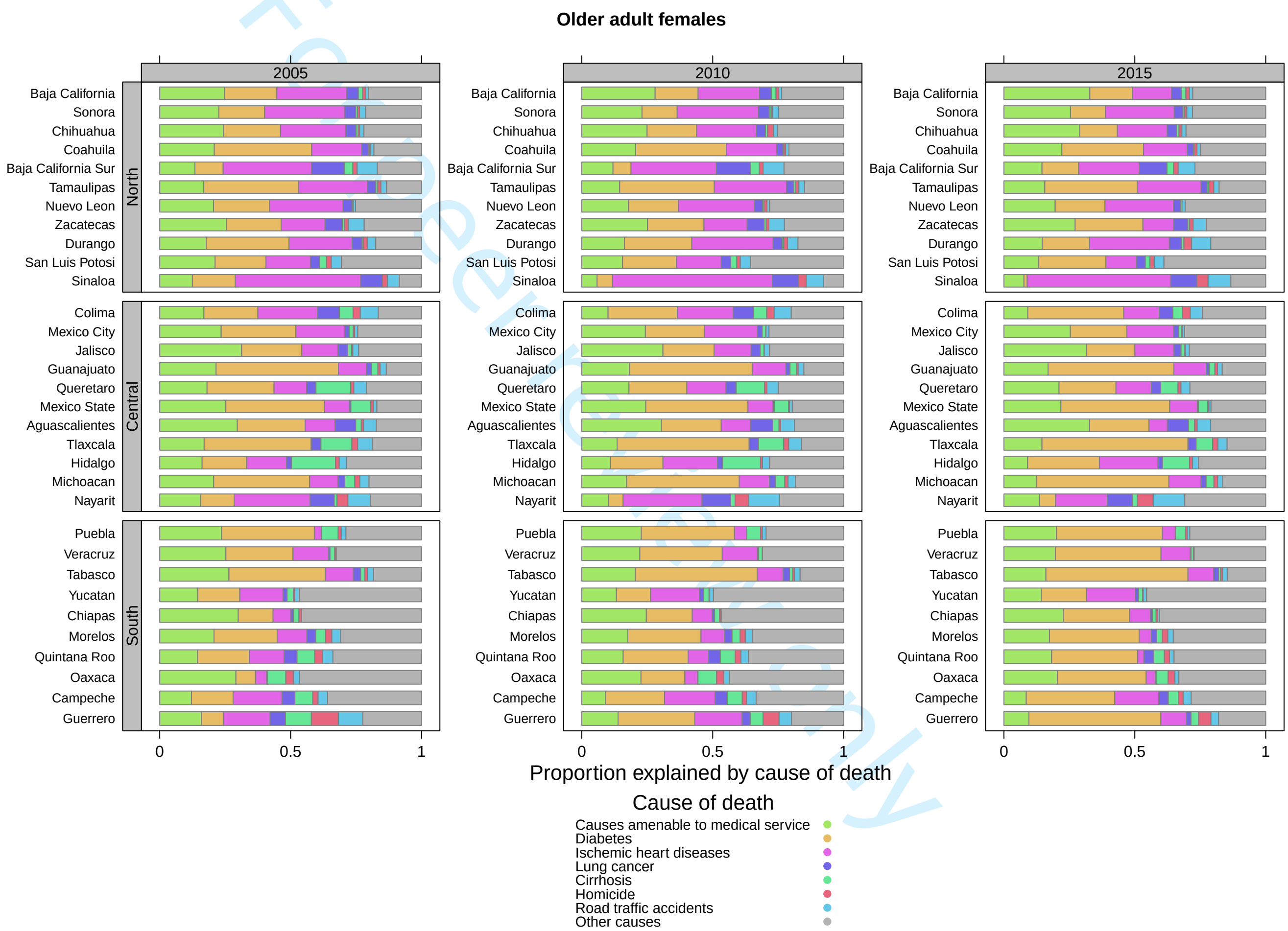


Figure 18: Proportion by cause of death from benchmark mortality for older female adults (ages 50-84). Source: own calculations.



BMJ Open

Inequalities and deterioration in average lifespan among adults in Mexico, 1990-2015: A cross-sectional demographic cause-of-death analysis

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Primary Subject Heading:	Public health
Secondary Subject Heading:	Epidemiology, Global health, Health policy
Keywords:	health inequality, adult health, mortality, homicides, avoidable mortality

Title: Inequalities and deterioration in average lifespan among adults in Mexico, 1990-2015: A cross-sectional demographic cause-of-death analysis

Authors: José Manuel Aburto, *PhD student* (JMA)[a*†], Tim Riffe, *Research Scientist* (TR)[b†] & Vladimir Canudas-Romo, *Associate Professor* (VCR)[c]
Author affiliations:
[a] Institute of Public Health-Unit of Biodemography, University of Southern Denmark, Odense 5000, Denmark.
[b] Max Planck Institute for Demographic Research, Rostock 18057, Germany
[c] School of Demography, Australian National University, ACT 0200, Australia
[†] These authors contributed equally to the paper
[*]The manuscript's guarantor.

Corresponding author: José Manuel Aburto: jmaburto@health.sdu.dk, T: +45 65509416

Keywords health inequalities, adult health, , mortality, violence, avoidable mortality

Abstract

Objective: To quantify the effect of medically-amenable conditions, diabetes, ischemic heart diseases, lung cancer, cirrhosis, suicides, homicides and road-traffic accidents on longevity in Mexico during 1990-2015.

Design: Retrospective cross-sectional demographic analysis using aggregated data.

Setting: Vital statistics from the Mexican civil registration system.

Participants: Aggregated national data (from 91.2 million people in 1995 to 119.9 in 2015) grouped in 64 populations (32 Mexican-states [including Mexico City] by sex) with cause-of-death data.

Main outcome measures: Cause-specific contributions to the gap in life expectancy in three age groups (0-14, 15-49 and 50-84) with a low-mortality.

Results: The population below age 15 shows improvements in survival. Average survival below 15 over states was 14.82 (95% confidence interval, 14.76 to 14.88) and 14.78 years (14.70 to 14.86) in 2015, for females and males respectively. However, the adult population aged 15 to 49 shows deterioration among males after 2006 in almost every state due to an increasing homicides and a slow recovery thereafter. Out of 35 potential years, females and males live on average 34.57 (34.48 to 34.67) and 33.80 (33.34 to 34.27), respectively. Adults aged 50 to 84 show an unexpected decrease in the low mortality benchmark, indicating nationwide deterioration in both females and males with average survival of 28.59 (27.43 to 29.75) and 26.52 (25.33 to 27.73) out of 35, respectively. State gaps from the benchmark were mainly caused by ischemic heart diseases, diabetes, cirrhosis and homicides. We find large health disparities between states, particularly for the adult population after 2005.

Conclusions: Mexico has succeeded in reducing mortality and between-state inequalities in children. However, the adult population is becoming vulnerable as it has not been able to reduce the burden of conditions amenable to health services and violence. This has led to large health disparities between Mexican states in the last 25 years.

Strengths and limitations of this study

- We analyze nine cause-of-death groups using the concept of avoidable/amenable mortality that enables us to capture recent changes in mortality in Mexico.
- We introduce a methodology to quantify the impact of medically amenable mortality and behavior related conditions on life expectancy relative to a low mortality benchmark.
- We analyze patterns in life expectancy for different age groups over time (1995-2015) and simultaneously account for changes in causes of death and inequality between states that have undergone major social and public health transitions.
- Mortality data from Mexico are likely to present inaccuracies in cause-of-death classification due to comorbidities, particularly at older ages.
- Our estimates regarding homicide mortality are likely to be underestimated due to inaccurate practices regarding counting, reporting, and due to the large number of missing individuals in Mexico

Introduction

The second half of the 20th century was marked by sizable improvements in mortality, living conditions, and health in most Latin American countries.[1] In Mexico, these improvements have slowed down recently due to opposing trends in particular causes of death. For instance, homicide and diabetes increased during the first decade of the 2000's, even as infectious and respiratory diseases continued to fall over the same period. While life expectancy at birth increased by 4.3 years for males (from 67.6 to 71.9) and 3.4 years for females (from 73.8 to 77.2) between 1990 and 2000,[2] between 2000 and 2010, life expectancy at birth entered into a period of stagnation for males and slowed progress for females.[3]

This period coincides with ongoing public health interventions, such as the Universal Vaccination Program and stablished health systems (IMSS, ISSSTE), and with the implementation of a Universal Health Coverage program (*Seguro Popular*). The latter program provides primary and secondary health care to the uninsured population and allocates funds to cover catastrophic health expenditures.[4] Further, since 1997 conditional cash transfer programs were introduced to supply incentives for poor families to invest in education, health, and nutrition.[5] Some evidence suggests that Mexico experienced substantial decreases in infant and child mortality, and in the prevalence of acute malnutrition between 1980 and 2000 thanks partially to these interventions.[6] Similarly, by 2012 *Seguro Popular* had provided health insurance coverage to an additional 52 million people in Mexico (or 44.4% of the population), leading to increased access to public health care and protection from the financial consequences of disease.[7]

Conditional cash transfers have focused on the poorest states, and *Seguro Popular* was introduced at different times in different states across the country. Although these actions underscore broad progress in public health interventions, they mask disparities between Mexican states and the epidemiological patterns for different age groups. For instance, Mexico faces a rapid aging process in which the interaction between infectious diseases and noncommunicable conditions can be anticipated in the adult population[i].[8] Therefore, it is necessary to assess the varied impacts that these interventions may have had on mortality in Mexican states at different ages.[9]

One approach to approximate the impact of health care and other interventions, and to reveal potential areas of improvement is by operationalizing the concept of Avoidable or Amenable Mortality (hereafter abbreviated AM).[10 11]This categorization of mortality aims to measure the quality of health service systems by selecting certain causes of death that should not occur in the presence of effective and timely health care. Therefore, improvements in AM mortality are expected over time, as has been observed in several countries. For example, among 19 industrialized countries, including 14 countries from Western Europe, USA, Canada, Australia, New Zealand and Japan, a reduction in AM rates was observed over the past 20 years.[10] Avoidable mortality rates fell, on average, by 17% for males and 14% for females in these countries between 1997 and 2003. However, the USA lagged behind the other countries in this group, while Japan, France and Australia were the top performers. Despite mortality reductions from cancers and circulatory diseases for both sexes, disparities between countries persist, with the United States showing the smallest reductions (around 5%) for both sexes.[10]

In Mexico, the components of avoidable mortality had different trends since the late 1990's. Mortality from infectious diseases and nutrition-related conditions decreased between 2000 and 2004,[12] while deaths related to diabetes and ischemic heart diseases increased in the first decade of the 2000s.[13] Importantly, increases in the latter causes of death were concentrated in the poorest states of the country.[13]

The objective of this research is twofold. Firstly, analysing mortality trends by cause of death for all 32 Mexican states, by sex, and over the full period from 1990 to 2015. Thereby complementing previous studies focusing on earlier years of the 21st century.[3 13-16] This choice of period covers several public health interventions and captures several major trends in state and cause-of-death variation. We further segment AM into health intervention-related and behavior-related AM causes that capture the epidemiological patterns of Mexico.[14] Secondly, our work differentiates from earlier studies by comparing state mortality patterns with an easy-to-understand low-mortality benchmark calculated for large age groups (i.e. 0-14, 15-49 and 50-84). This concept has been previously used in mortality studies.[17-19] Deviations from the low-mortality benchmark indicate a strong potential for improvement.

We hypothesize age-dependent variations in mortality outcomes. In particular, we expect convergence between states and improvement in survival for young people, since public health interventions are mainly focused on infant and child health. For instance, the vaccination program and *Seguro Popular* aim to fully cover children in the entire country, and recent evidence suggests a decrease in mortality below age 15 due to a decline in infectious and respiratory diseases.[20] On the contrary, we expect little improvement in survival for the young-adult population due to the sudden and egregious rise in homicide mortality.[21] We foresee health deterioration among older adults due to documented increases in diabetes mortality.[20] Although every state has the commitment to provide universal coverage and equitable access to health care, we anticipate disparities in mortality improvements between states due to heterogeneous epidemiological transitions among states,[16] and differences in how health care programs have been delivered to the population.[22]

Data sources & methods

Our analyses are based on publicly available anonymized datasets. We used death register microdata files produced by the Mexican Statistical Office (INEGI) for years 1990 to 2015.[23] From these data, information on causes of death by single age, sex, and state of residence at the time of death was extracted. Population estimates from 1990 to 2015 came from the Mexican Population Council (CONAPO).[24] These population estimates adjust for age misstatement, undercounting, and interstate and international migration. Death counts and estimates of the population exposed to risk were used to calculate cause-age-specific death rates by sex for each state from 1990 to 2015.

Classification of Causes of Death

To classify deaths we use the concept of “Avoidable/Amenable” Mortality (AM).[10 11] We group causes of death into nine categories based on previous classifications that has recently been adapted to the case of Mexico.[14] The first category refers to those conditions that are susceptible to medical intervention, such as infectious and respiratory diseases, some cancers and circulatory conditions, and birth conditions, among others. It is labeled “Causes amenable to medical service”. We separate diabetes, ischemic heart diseases (IHD), lung cancer, and cirrhosis as subcategories of AM because these causes are susceptible to both health behavior and medical service, and because the first two represent major causes of death in Mexican adults.[16] Likewise, we separate homicide, suicide and road traffic accidents because they have emerged as leading causes of death among young people, and the first one recently had a sizeable impact on life expectancy in Mexico.[14] Remaining causes were grouped into a single category labeled “Other causes”.

Death data were originally classified according to the International Classification of Diseases (ICD), revision 9 for years 1990 to 1997 and revision 10 for 1998 to 2015 (see Additional file 1 Table 1 for details on ICD codes for each category). To check the validity of these cause-of-death codes in Mexico, we performed a sensitivity analysis and did not find major ruptures in mortality trends by AM classification (See Additional file 1, Figure 1).

Comorbidity in the old age population has increased in Mexico.[25] As a result inaccuracies may arise in cause of death registration due to problems associated with medical diagnosis, and selection and coding of the main cause of death. Although analyses in these ages should consider multiple causes of death to better represent old age mortality, it is out of the scope of this study since we focus on the primary cause of death. We truncate our analysis at age 85 to avoid misinterpreting results related to inaccurate cause of death coding practices.

Age groups

We calculate life expectancy in three large age groups to capture mortality differences along the life course. Life expectancy in each age group simply refers to the average years of life lived between two ages conditional on survival to the lower age bound. This measure is also known in demographic analysis as temporary life expectancy.[26] The first age group refers to people aged 0-14. This group is likely to represent improvements in causes amenable to medical service (e.g. infectious diseases and conditions of perinatal period).[3] The second group, aged 15-49, is used to capture the effect of homicide mortality and external causes historically related to the young-adult mortality hump, as well as maternal mortality for women.[27] This age group had an important impact on changes in state life expectancy in the first decade of the 2000s.[14] The third group covers older adults aged 50-84; with similar life expectancy (ages 40-84) used for international cancer comparisons.[28] Older adults are likely to represent a vulnerable group due to deterioration in non-communicable diseases and injury-related mortality in recent years.[16 29]

Low mortality benchmark

Our low-mortality benchmark is calculated on the basis of the lowest observed mortality rates over all states by age, year, cause, and sex. Subsequently, life expectancies are calculated with these rates. This represents the highest potentially achievable life expectancy from the aggregated low mortality profiles. This benchmark is a practical reference because it is based neither on a projection of improvements into the future nor on an arbitrary and likely dissimilar population. The resulting minimum mortality rate schedule has a unique age profile, and it determines our benchmark temporary life expectancy. It can be treated as the best presently achievable mortality assuming perfect diffusion of the best available practices and technologies in Mexico.[19]

Methods

Cause-specific death rates are the basis of all calculations in this work. To mitigate random variations over time and correct for age-heaping, these rates are adjusted in two steps. First, we smooth cause-specific death counts over age and time for each state and sex separately using a 2-d p-spline.[30] Second, we rescale the smoothed cause-specific death rates to sum to the raw all-cause death rates for each sex and state. Period life tables up to age 84 for males and females from 1990 to 2015 and their benchmarks were calculated following standard demographic methods (for life table construction see Chapter 2 of reference 32).[31 32] Temporary life expectancies were calculated [26](see Additional file 1 for a technical overview and 95% CIs) and cause-specific contributions to the difference between each state and the low mortality benchmark were estimated using standard decomposition techniques.[33] The decomposition method used in this analysis is based on a model of demographic functions that change gradually over time.[33] It is a stepwise-based demographic method and has been successfully used to decompose age and cause-specific effects on life expectancy.[34] We provide a short description in the Supplemental

Material and the results are fully reproducible from the R-code provided in the Data Sharing statement. Finally, the coefficient of variation of the gap between temporary life expectancy in each age group with the low mortality benchmark was calculated to measure the level of disparity between states over time. This indicator is relative and has the property that even if temporary life expectancy refers to different age-ranges, i.e. 0-14,15-49, and 50-84, the values are still comparable over age-groups and time. In addition, we performed two-way ANOVA and post hoc tests to analyze disparities in temporary life expectancy between states and age groups in Mexico.

Patient involvement

No patients were involved in setting the research question, outcome measures, design of the study. No patients were asked to advise on the interpretation of the results and there are no plans on disseminating the results of this research to study participants or the relevant patient community.

Results

Trends in life expectancy for Mexican states by age-groups

Figure 1 presents the temporary life expectancies by state for three large age groups: the youngest (ages 0-14), young adults (15-49) and older adults (50-84), over the period 1990-2015. Grey lines refer to each of the 32 states; the black lines represent the average over states; and the blue lines represent the low mortality benchmark. The black line at the top of each panel indicates the maximum livable years in each age group: 15 for the youngest, and 35 for young and older adults conditional on surviving to ages 15 and 50, respectively. Any gap between a state line and the blue line represents potential additional years of life if mortality were to achieve the low mortality benchmark.

All states show improvements in the youngest age group since 1990, approaching the low mortality benchmark, which itself is very close to maximum survival below age 15. This was observed even in the southern states such as Puebla, Chiapas and Tabasco which have lagged in reducing mortality at these ages throughout the entire period.

Life expectancy between ages 15 and 49 shows a sudden drop after 2005 among males in almost every state in Mexico. In 2005, young males in this age group had a temporary life expectancy of 33.9 years (95% CI, 33.5 to 34.2) averaged over states. By 2010, the number of states below this level had increased from 14 to 23. Chihuahua, Sinaloa and Durango, in the northern region, experienced a substantial mortality shock in 2010 in this age group, and consequently recorded the largest departures from the low mortality benchmark. In 2015, the state average (33.8 years, 33.3 to 34.3) had almost recovered to its 2005 level. Trends for females are closer to the low mortality benchmark.

Among older adults, life expectancy between ages 50 and 84 shows stagnation and deterioration over the entire period of observation. Even the low mortality benchmark exhibits a gradual downward trend, pointing to a generalized mortality increase. The female state average life expectancy declined from 28.8 years (27.4 to 30.2) in 1990 to 28.3 years (27.4 to 29.2) in 2010. By 2015, this average only managed to recover to 28.6 years (27.4 to 29.8). Among males, the average over states decreased from 26.7 years (24.7 to 28.8) in 1990 to 26.3 years (24.9 to 27.6) in 2010, and 26.5 years (25.3 to 27.7) in 2015. Furthermore, we fitted three linear models to both sexes, combined and independently, and the slope coefficient was significant in all of them at the level of $p < .005$. These results suggest that the decline observed was significant. As with young adult males, some states experienced deterioration after 2005, with a minor recovery since 2010.

[Figure 1 about here]

Health disparities between states and age groups

Figures 2-5 show results for males because they exhibit the largest departures from the low mortality benchmark and higher inequality. However, results for females are shown in the Additional file 1.

Figure 2 shows trends in inequalities between states in Mexico for males in the three age groups, as measured by the coefficient of variation (results for females are reported in Additional file 1, Figure 2). This indicator measures the variation in the gap of temporary life expectancy with the low mortality benchmark between states within the three age groups. Larger values are related to higher disparities between states. Trends show mixed patterns of convergence with temporary divergence, and with females in all cases showing less between-state inequality than males over the entire period studied.

There are important differences in inequality levels and trends between age groups. Since 1990, state inequality in life expectancy in the youngest age group has been decreasing. Among females, young adults show even lower values than the population in the youngest age group. However, for males in the young adult age-group a crossover in the early 2000's is seen, with the coefficient of variation increasing after 2005. The highest values are observed in the period 2009-2011. By 2015, state inequalities among young adults had decreased substantially, but still remain higher than that of the youngest age group. Older adults show substantially higher inequality than the other age groups over the entire period studied, but also show steady convergence between states. From 2013, both males and females show a potential rise in disparities between states, although could be random variation since it only accounts for 2 years (Additional file 1 Figure 2).

[Figure 2 about here]

To illustrate discordance between age groups within each state, Figure 3 shows the state ranking of temporary life expectancy for the years 2010-15 for males in each age group (see Additional file 1, Figure 3 for females' results). States at the top show the highest values in temporary life expectancy, while states in the bottom refer to the lowest values. We chose to highlight the states with most discordant age-rankings. Green and purple lines refer to selected states that show drastic changes in the ranking between different age groups. For example, Sinaloa, in the northern part of Mexico, holds the record life expectancy below age 15; however, young adults (15-49) show one of the lowest values, while older adults are in the sixth position out of 32. Similar trajectories are shown with green lines for Nayarit and Michoacán in the central region, Zacatecas in the North, as well as Morelos and Guerrero from the southern region. Conversely, the pattern of age discordance in Hidalgo, Querétaro and Mexico City from the central region, and Yucatan and Puebla in the South (purple lines) is summarized by changing from a low rank in the youngest age group to a high rank in young adults, followed by low rank in older adults.

We performed a two-way ANOVA on temporary life expectancy by state and age-groups controlling for year. There was a statistically significant interaction between the effects of states and age groups [$F=12.25$, $p < .001$] indicating, as shown in Figure 3, that part of the existing variation in the country is due to within-variability in each state. There were also significant differences in temporary life expectancy between age groups [$p < .001$] and states [$p < .001$] reflecting between-state variability, as shown in Figure 2.

[Figure 3 about here]

Cause-decomposition analysis

In Figures 4 and 5, the Mexican states in each region are arranged according to the largest gap with the low mortality benchmark among older adult males in 2015. Figure 4 shows how causes amenable to medical service, diabetes, ischemic heart diseases (IHD), lung cancer, cirrhosis, homicide, and road traffic accidents contributed to the gap between each state and the low mortality benchmark from 1990 to 2015 for male older adults (ages 50-84). These are the causes of death that contributed the most to holding states back from achieving the low mortality benchmark. Light-yellow colors indicate negligible contributions, which means that are very close to the low mortality benchmark within each category. Darker red hues indicate larger contributions to the gap. If a particular state is improving during the period, it shows a transition from red to light-yellow.

Medically amenable causes of death show gradual improvements in most states from 1990 to 2015, bringing them closer to the benchmark in this category. However, large disparities between states and potential for improvements remain. For example, Baja California, Sonora, Chihuahua and Coahuila from the northern region show substantial contributions to the gap. Diabetes mortality has increasingly contributed to widening the benchmark gap in several states, including Coahuila and Tamaulipas in the North, Mexico City, Guanajuato, Mexico state and

Tlaxcala in the central region, and Puebla, Veracruz and Tabasco in the South. Similarly, IHD significantly affects the northern part of the country, while cirrhosis is mostly concentrated in the South. Lung cancer and road traffic accidents have lower contributions to the benchmark gap, but these remain important causes of death. Homicides increased the gap in this age group in some states after 2005, such as Chihuahua, Durango and Sinaloa in the North, Colima, Michoacán and Nayarit in the central region, and Guerrero in the South.

[Figure 4 about here]

Females show similar regional patterns to males, albeit of lower magnitude. For males, causes amenable to medical service, diabetes, and IHD contributed the largest share to the gap with the low mortality benchmark among older adult females. In the youngest age group, improvements in life expectancy and in reducing the gap with the low mortality benchmark were mainly driven by causes amenable to medical service among both females and males. Finally, homicide mortality and road traffic accidents are the main drivers of the gap with the benchmark among young male adults (ages 15-49). Importantly, homicides contributed more than 2.5 years to the gap with the low mortality benchmark in 2010 in the northern state of Chihuahua, and several states from the North and South of Mexico showed substantial impacts from homicide after 2005. Results for all age-groups are shown in Additional file 1, Figures 4-9.

Potential gains and causes of death in 2015

Figure 5 breaks down the state-specific low mortality benchmark gap for males aged 50-84 into potential gains and their cause of death composition. The left panel shows the potential gains for older adults if the low mortality benchmark were achieved for each state in 2015. The right panel shows the proportion of potential gains due to specific causes of death in the same year.

Every state in Mexico could increase survival by at least one year in older adult ages if they were to achieve the low mortality benchmark. However, for 17 of them the gap with the benchmark is higher than 2 years, and for 3 states in the northern region it is greater than 3 years. For females, with the exception of Sinaloa and Nayarit, all the states show the potential to gain over an additional year of life between ages 50-84.

More than half of these potential gains in life expectancy between ages 50 and 84 are due to medically amenable causes, diabetes, IHD, and cirrhosis in every state in Mexico (right panel). This is true also for females. Although older males show lower impact of homicide mortality on potential gains compared to young adult males (15-49), its effect is present in almost every state, particularly in Guerrero, Morelos in the South, Nayarit and Colima in the central region, and Sinaloa in the North. Results for all the age groups for the years 2005, 2010, and 2015 are shown in the Additional file 1, Figures 10-18.

[Figure 5 about here]

Discussion

In Mexico since 1990, life expectancy in three large age groups has followed discordant patterns of rise, stagnation, and deterioration. Such patterns have been driven mainly by causes of death that are amenable to medical service (such as infectious and respiratory diseases) and health behaviors (such as homicides, suicide, diabetes, IHD, and cirrhosis) as subcategories of the broader concept of Avoidable/Amenable mortality (AM). Patterns in these two large cause-of-death categories led to contrasting levels of inequality in the country.

Life expectancy below age 15 converged towards the low mortality benchmark and maximum survival in all 32 Mexican states. These results underscore public health interventions aimed at youngest ages. This is supported by evidence that vaccination coverage has been achieved for the entire young population, and that health insurance coverage has improved, due to vaccination programs and the implementation of *Seguro Popular* along with previous established health systems, respectively.[9] Causes amenable to medical service are at the heart of such improvements, consisting of decreases in infectious and respiratory diseases associated with public health interventions targeting children.[6] For example, Puebla and Tlaxcala (in the South and central regions respectively) were the states with the lowest life expectancy below age 15 in 1990 and have improved by more than half a year since then. Moreover, the average over states improved from 14.5 in 1990 to 14.8 in 2015, with no state below 14.7. As a result of continuous and nationwide convergence towards the low mortality benchmark, inequalities between states in life expectancy below age 15 have been reduced.

Opposing the optimistic trend in the under-15 population, increases in homicide mortality reversed gains in male life expectancy, particularly between ages 15-49. These results are consistent with previous studies quantifying the effect of homicide mortality on the stagnation of national life expectancy at birth in the first decade of the 21st century,[3] and with the reversal experienced in life expectancy in most states between 2005 and 2010.[14] Our results extend such findings by adding five years of data and segmenting by specific age groups. We found that after ten years of the unexpected rise in homicide mortality, most states have experienced a slow and partial recovery since 2010. However, the impact of homicide is still higher than the levels observed in 2005. Between 2010 and 2015, this cause of death accounted for most of the gap between states and the low mortality benchmark in ages 15-49. For this age group, the states that show the greatest benchmark gap for homicide in 2015 are Guerrero in the South, and Sinaloa and Chihuahua in the North, which could gain one year, and half a year (each) respectively if homicides were reduced to the level of the southern state of Yucatán, which in this case makes up 100% of the benchmark. Moreover, health inequalities in life expectancy between states followed the rise in homicides after 2005 (Figure 2), and the considerable discordance between age-groups (Figure 3) was likely due in great part to homicide mortality in ages 15-49. It is unclear how these levels of state life expectancy will change with the new reports which highlight a three year increase in homicide in Mexico.[23,ii] Further, the exposure that people have had to violence has triggered mental health problems, e.g. population perceived vulnerability.[15] At the same time suicide is strongly linked to mental disorders.[35] Thus, if the Mexican health system does not have proper interventions to handle the mental health needs of the population, an increase in suicides might be observed in the future.

The population aged 50-84 shows the largest low mortality benchmark gap in both females and males. Out of 35 livable years in this age group, females lived on average 28.6 years and males 26.5 in 2015 without any clear improvement in the 26 years since 1990. Even the low mortality benchmark itself shows a downward trend for males and females (Figure 1). Moreover, this age group exhibits the highest inequality between states in the last 26 years. Our results show that causes of death holding states back from the low mortality benchmark vary between regions. Causes amenable to medical service showed gradual improvements in almost every state since 1990. However, in some states of the northern region such as Baja California, Sonora, and Chihuahua, these causes of death still show large room for improvements among older adults. Diabetes, Ischemic Heart Diseases (IHD) and cirrhosis account for the majority of the gap with the benchmark mortality with large regional differences. For example, IHD is mostly concentrated in the North (Figure 4), while cirrhosis and diabetes show a stronger impact in the central and southern regions. These results are supported by previous evidence documenting an increase in adult mortality rates from chronic kidney disease, diabetes, and cirrhosis since 2000.[16] Lung cancer and homicides had a lower impact on life expectancy for this age group, and both are higher in the northern part of the country.

Strengths and limitations of the study

The methodology we performed enables to measure the impact of medically amenable mortality and behavior-related mortality on life expectancy relative to a low mortality benchmark in three large age groups. It allows to analyze patterns in life expectancy for different age groups over time and simultaneously account for changes in causes of death and inequality between populations that have undergone major social and public health transitions. Therefore, it is imperative to consider the effect of different causes of death to estimate the effectiveness of public health and policy interventions.

The limitations of our study should be mentioned. First, Mortality data from Mexico are likely to present inaccuracies in cause-of-death classification due to comorbidities, particularly at older ages.[36] To mitigate this, we focus on ages below 85 and broad groups of causes of death. In addition, road traffic accidents and homicides may happen not in the place of residence but in another state, which might cause differences in state specific mortality. Moreover, our estimates regarding homicide mortality are likely to be underestimated due to inaccurate practices regarding counting, reporting, and due to the large number of missing individuals in Mexico.[37 38] Similarly, in 1997 a change in diagnosis criterion for diabetes took place, and this could have an impact on trends of mortality caused by diabetes in years adjacent to 1997.[39] In addition, underreported deaths and ill-defined causes of death could potentially bias our results. Mexico is among the countries with high-quality data according with the Pan American Health Organization's criteria. Underreported deaths are estimated to be around 0.8%,[40 41] while ill-defined causes of death represented 2.1% in the beginning of the century and has decreased to 1.7% more recently.[40] Therefore, we expect our main findings to hold given the small percentages of ill-defined and underreported deaths. Finally, small population sizes could bias our results. As a robustness check, we calculated Confidence Intervals (95%) for all our estimates of temporary life expectancy, including the benchmark (Supplementary material), and did not find major differences with our main results.

Avoidable mortality should be understood as an indicator of potential weaknesses with respect to health care and some public health policies and not as a definitive assessment.[10] The amount of deaths that should be considered within the avoidable classification is not clear [42]. For instance, some researchers consider only 50 percent of heart disease mortality to be avoidable.[43] [44] There is no direct information to precisely measure percentages of avoidable mortality within cause groups in Mexico. Nonetheless, the difference between a given mortality schedule and the best mortality schedule of the same year can be conceived of as a minimal definition of avoidable mortality. The benchmark mortality schedule sets a lower bound to how much mortality could have been avoided. Certainly, even the best mortality schedule will contain elements of mortality that most would consider avoidable. To the extent that the components of the benchmark schedule were indeed attained somewhere in Mexico, one can view any excess mortality with respect to the benchmark schedule as avoidable. We believe this perspective improves on the AM concept by giving a directly measurable standard against which to estimate avoidable deaths.

Implications of findings

Beyond the mortality implications of the rise in homicide, violence has had a toll on perceived vulnerability in the country.[15] The recent increase in homicides in some states could trigger an increase in the perception of vulnerability, which would result in a higher average lifetime fear in specific states. Although we are not able to link the trends in mortality among young adults in Mexico with specific public policies, some evidence suggests that the propagation of homicide mortality is not only a result of the war between drug cartels, but also because of the implementation of specific policies aimed to mitigate drug cartel operations after 2006.[45] There is no simple way to lessen the impact of homicide mortality, but it is clear that the government has not been able to reduce its burden back to levels observed before 2005. Furthermore, state homicide rates may underestimate the effect of violence in particular localities. For example, Guerrero in the South, has two of the most dangerous cities in the world,[iii] but no information is available on the heterogeneity in homicide mortality for the rest of the state.

The fact that in 2015 the older adult population of Mexico could add more than one year of life in every state for males, and in 30 states for females by achieving the benchmark mortality levels, underscores vulnerability in these ages. Public health interventions targeting specific causes of death for this age group according to the epidemiological profile of each state would not only increase life expectancy, but it would also forge a path towards more equality between states in health outcomes. More than 50% of the potential gains in life expectancy between ages 50 and 84 are due to avoidable mortality, and to a large extent mortality related to health behaviors and medically amenable causes. For instance, obesity and overweight, risk factors for diabetes and IHD, have dramatically increased since the 1990s in developing countries because of the consumption of cheap, energy-dense food and reduced physical activities.[46] In this sense, Mexico, along with the USA, has the highest rates of overweight and obesity among all OECD countries[20] and one of the highest in Latin America, along with Chile, El Salvador, Honduras, and Paraguay.[47] However, obesity prevalence is not homogeneous across Mexico. The highest rates of obesity are concentrated in the northern and central regions[20] and in urban areas of the country,[48] which roughly matches our regional pattern of IHD and diabetes mortality.

Conclusion

Mexico stands today at an advanced stage of the epidemiological transition.[16] However this transition was achieved rapidly and the health system is ill-prepared for the burden of non-communicable diseases.[49] The cardiovascular mortality reductions that brought the developed world into advanced levels of life expectancy trends, still are in progress in Mexico. Nevertheless, no single solution is available to reduce behavioral mortality in this country since, as we show, great heterogeneity in mortality levels exist among its states.

Signs of a fragile situation in the health and mortality of the oldest age groups is observed in the decline in the low mortality benchmark used in our analysis. The aging of the population could scale up this situation if timely preventive measures are not put in place. Furthermore, a resurgence of violent deaths [14 15 21] has created a new burden in Mexican society.

As many developing countries, Mexico will have to face these new challenges with a broad strategy. This should include a continuous and adaptable health system ready for the current and future health adversities at the physical, mental and societal levels. Many other institutions will also have to coevolve including importantly the development of an education system that embraces and encourages physical and healthy activities to diminish risk factors that contribute to the high prevalence of obesity and cirrhosis in Mexico. Finally, the burden of violence in recent years demonstrates the failure of current policies trying to mitigate violence in the country. New strategies that replace current ones are needed and embracing evidence based policies (e.g. drug policies) could be a new venue to eradicate the consequences of violence on the Mexican population.

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Data sharing: All data used are publicly available in references 22 and 23. All the study is fully replicable at https://github.com/jmaburto/DecompMex

Transparency: The lead author* affirms that this manuscript is an honest, accurate, and transparent account of the study being reported; that no important aspects of the study have been omitted; and that any discrepancies from the study as planned (and, if relevant, registered) have been explained.

Ethical approval: No ethical approval was needed from the institutions' boards since we work with anonymized aggregated publicly available datasets.

Figures

Figure 1. State-specific life expectancy trends (grey), average (black) and low mortality benchmark (blue) for three age groups, the youngest (0-14), young adults (14-49), and older adults (50-84) by sex for the period 1990-2015. Source: calculations based on INEGI and CONAPO files.

Figure 2. Inequality in male life expectancy between states for the youngest (0-14), young adults (15-49) and older adults (50-84), 1990-2015. Source: calculations based on INEGI and CONAPO files.

Figure 3. Discordant age-rankings for average male life expectancy 2010-15 for the youngest (0-14), young adults (14-49), and older adults (50-84). Source: calculations based on INEGI and CONAPO files.

Figure 4. Cause-specific contributions to the gap between states and low mortality benchmark for older male adults (50-84), 1990-2015. Source: calculations based on INEGI and CONAPO files.

Figure 5. State-specific gap with the low mortality benchmark and its cause-of-death composition for older male adults (50-84) in 2015. Source: calculations based on INEGI and CONAPO files.

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Endnotes

[i] The percentage of the population aged 65 or older is projected to go from 6.0% in 2015 to 10.2% in 2030 (Reference: CONAPO)

[ii] [https://www.businessinsider.com.au/homicides-hit-new-high-mexico-alongside-increase-in-robberies-2017-11?r=US&IR=T]
[iii] [http://www.economist.com/blogs/graphicdetail/2017/03/daily-chart-23]

Additional Files

Additional fille 1 | Supplemental material

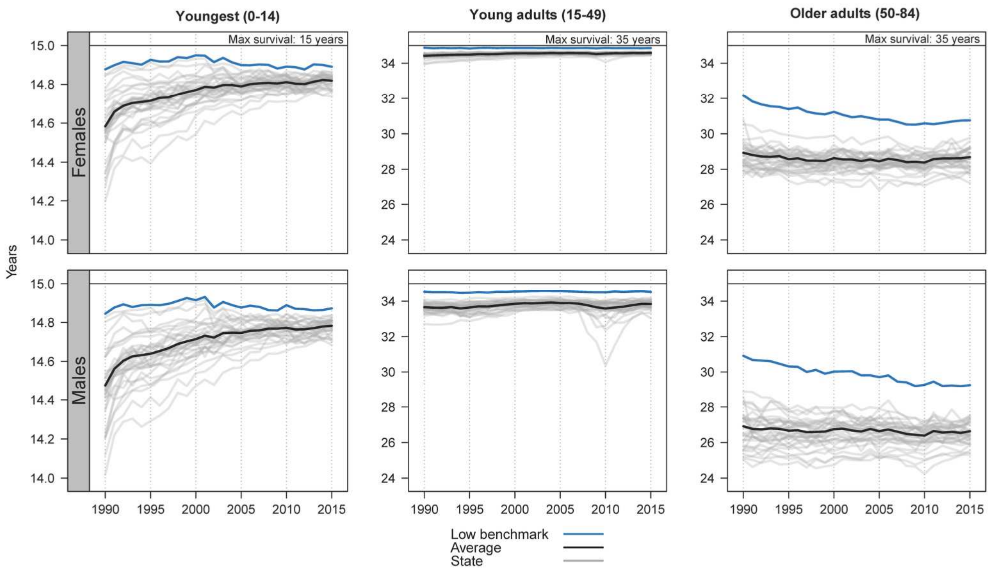

Figure 1. State-specific life expectancy trends (grey), average (black) and low mortality benchmark (blue) for three age groups, the youngest (0-14), young adults (14-49), and older adults (50-84) by sex for the period 1990-2015. Source: calculations based on INEGI and CONAPO files.

177x103mm (300 x 300 DPI)

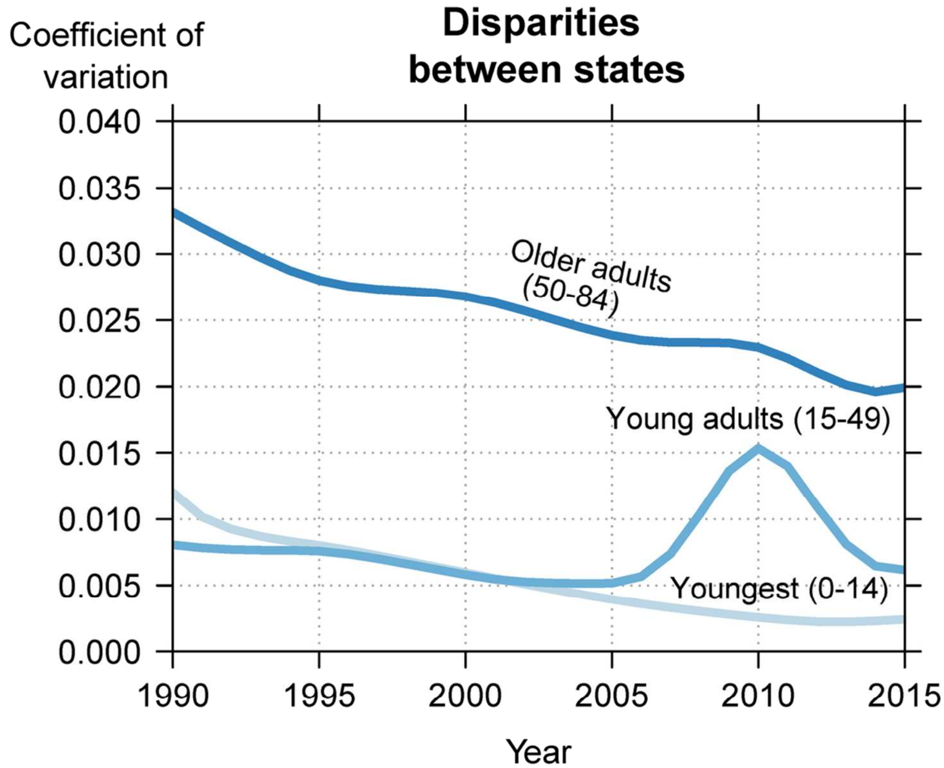

Figure 2. Inequality in male life expectancy between states for the youngest (0-14), young adults (15-49) and older adults (50-84), 1990-2015. Source: calculations based on INEGI and CONAPO files.

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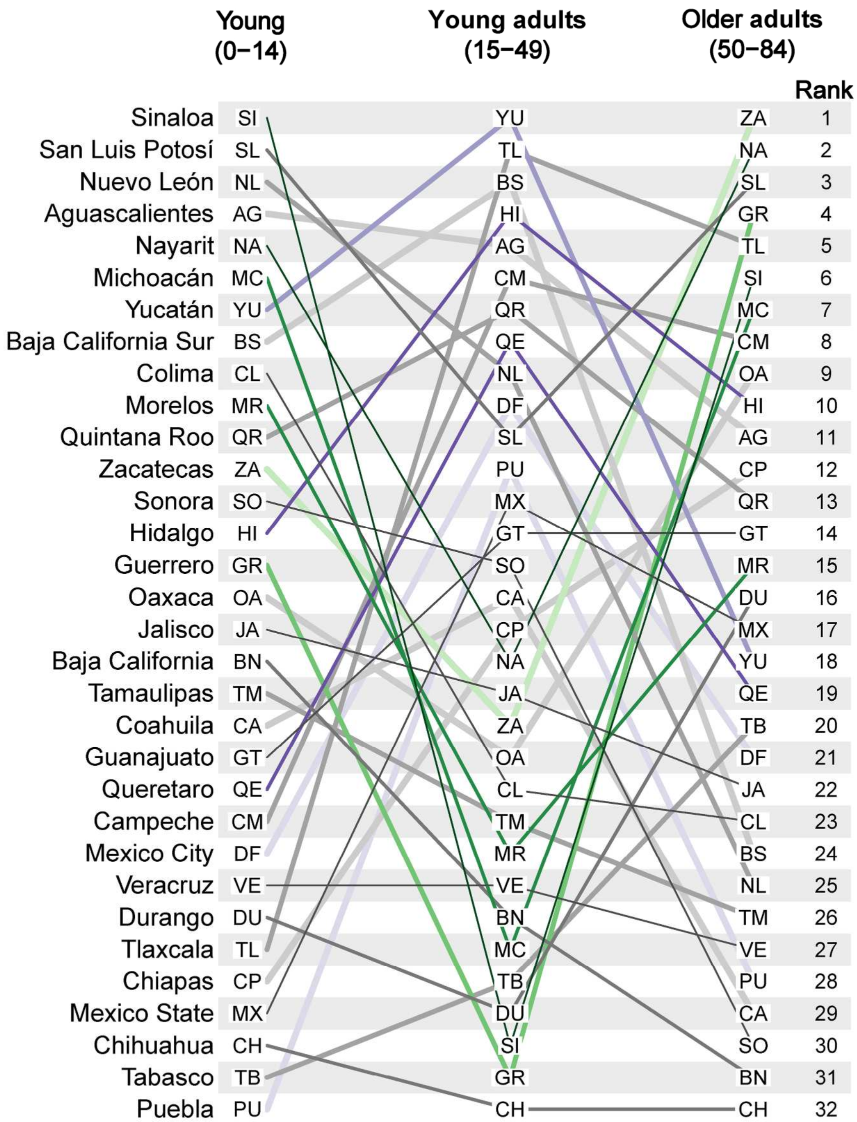

Figure 3. Discordant age-rankings for average male life expectancy 2010-15 for the youngest (0-14), young adults (14-49), and older adults (50-84). Source: calculations based on INEGI and CONAPO files.

203x270mm (300 x 300 DPI)

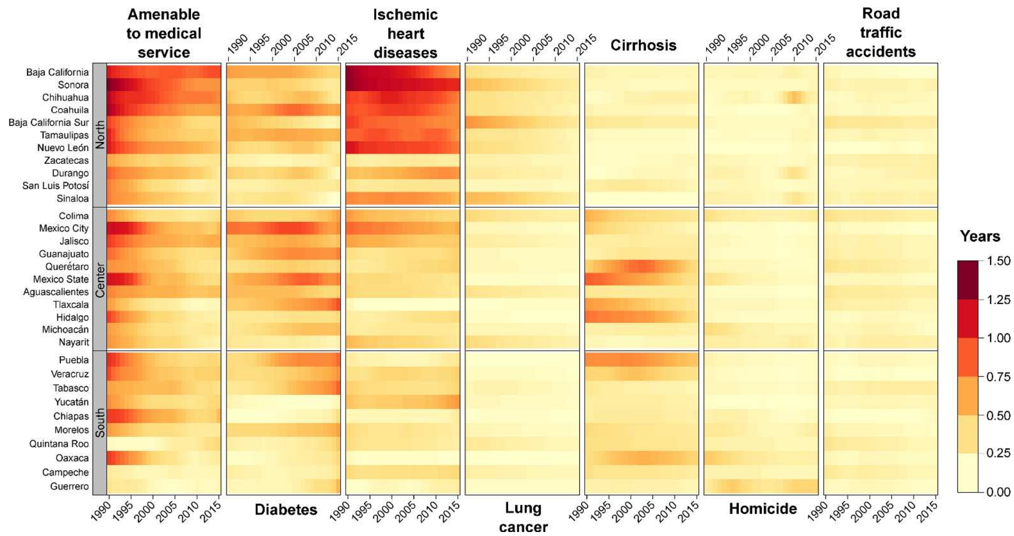

Figure 4. Cause-specific contributions to the gap between states and low mortality benchmark for older male adults (50-84), 1990-2015. Source: calculations based on INEGI and CONAPO files.

511x267mm (300 x 300 DPI)

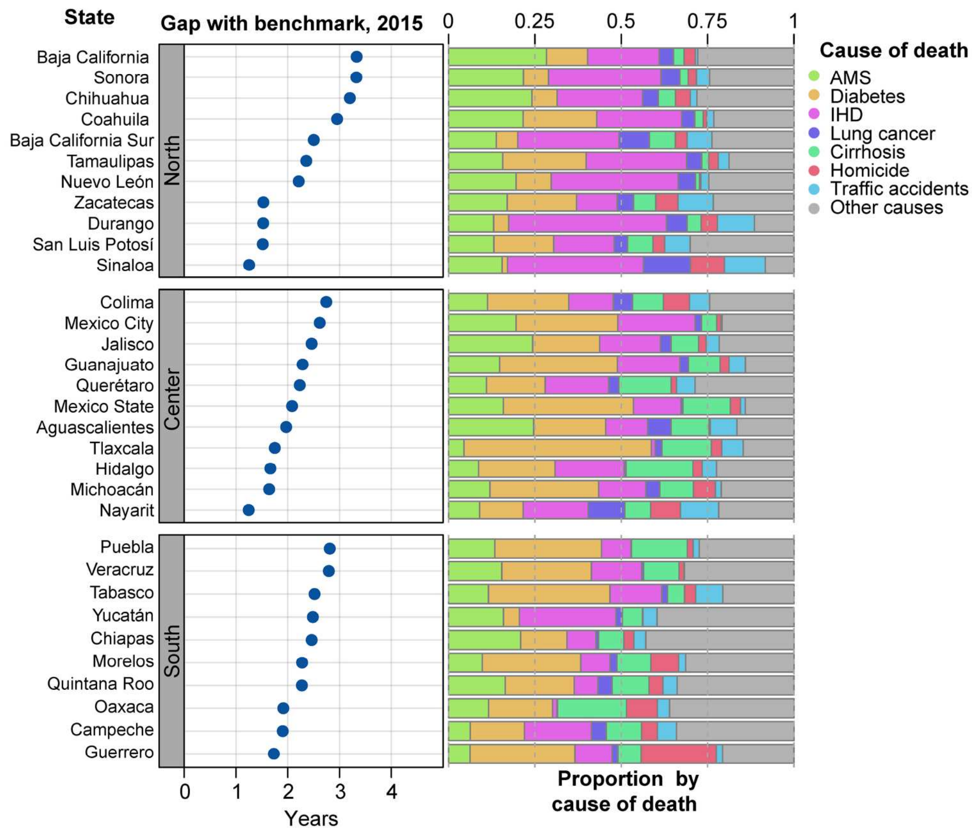

Figure 5. State-specific gap with the low mortality benchmark and its cause-of-death composition for older male adults (50-84) in 2015. Source: calculations based on INEGI and CONAPO files.

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Inequalities and deterioration in average lifespan among adults in Mexico, 1990-2015:A cross-sectional demographic cause-of-death analysis

José Manuel Aburto[1], Tim Riffe[2], and Vladimir Canudas-Romo[3]

[1]University of Southern Denmark
[2]Max Planck Institute for Demographic Research
[3]School of Demography, Australian National University

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Abstract

Objective: To quantify the effect of medically-amenable conditions, diabetes, ischemic heart diseases, lung cancer, cirrhosis, suicides, homicides and road-traffic accidents on longevity in Mexico during 1990-2015.

Design: Retrospective cross-sectional demographic analysis using aggregated data.

Setting: Vital statistics from the Mexican civil registration system.

Participants: Aggregated national data (from 91.2 million people in 1995 to 119.9 in 2015) grouped in 64 populations (32 Mexican-states [including Mexico City] by sex) with cause-of-death data.

Main outcome measures: Cause-specific contributions to the gap in life expectancy in three age groups (0-14, 15-49 and 50-84) with a low-mortality.

Results: The population below age 15 shows improvements in survival. Average survival below 15 over states was 14.82 (95% confidence interval, 14.76 to 14.88) and 14.78 years (14.70 to 14.86) in 2015, for females and males respectively. However, the adult population aged 15 to 49 shows deterioration among males after 2006 in almost every state due to an increasing homicides and a slow recovery thereafter. Out of 35 potential years, females and males live on average 34.57 (34.48 to 34.67) and 33.80 (33.34 to 34.27), respectively. Adults aged 50 to 84 show an unexpected decrease in the low mortality benchmark, indicating nationwide deterioration in both females and males with average survival of 28.59 (27.43 to 29.75) and 26.52 (25.33 to 27.73) out of 35, respectively. State gaps from the benchmark were mainly caused by ischemic heart diseases, diabetes, cirrhosis and homicides. We find large health disparities between states, particularly for the adult population after 2005.

Conclusions: Mexico has succeeded in reducing mortality and between-state inequalities in children. However, the adult population is becoming vulnerable as it has not been able to reduce the burden of conditions amenable to health services and violence. This has led to large health disparities between Mexican states in the last 25 years.

Supplemental material

Appendix Table 1. Definitions of cause-of-death categories using the 9th and 10th revision of the International Classification of Diseases.

Category	ICD-10	ICD-9
I. Amenable to medical service		
I.A. AM-Infectious & respiratory diseases : intestinal infections, tuberculosis, zoonotic bacterial diseases, other bacterial diseases, septicemia, poliomyelitis, measles, rubella, infectious hepatitis, ornithosis, rickettsioses/ arthropod-borne, syphilis (all forms), yaws, respiratory diseases, influenza & pneumonia, chronic lower respiratory diseases	A00-A09, A16-A19, B90, A20-A26, A28, A32, A33, A35, A36, A37, A40-A41, A80, B05-B06, B15-B19, A70, A68, A75, A77, A50-A64, A66, J00-J08, J20-J39, J60-J99, J09-J18, J40-J47	001-009, 010-018, 32, 33, 37, 137, 020-027, 38, 45, 55-56, 70, 73, 080-082, 087, 090-099, 102, 460-479, 500-519, 480-488, 490-496
I.B. AM-Cancers: malignant neoplasm of colon, skin, breast, cervix, prostate, testis, bladder, kidney-Wilm's tumor only, eye, thyroid carcinoma, Hodgkins disease, leukemia	C16,C18-C21, C43-C44, C50, C53, C61, C62, C67, C64, C69, C73, C81, C91-C95	153-154, 172-173, 174, 180, 185, 186, 188-189, 190, 193, 201, 204-208
I.C. AM-Circulatory: active/acute rheumatic fever, chronic rheumatic heart disease, hypertensive disease, cerebrovascular disease	I00-I02, I05-I09, I10-I13, I15, I60-I69	390-392, 393-398, 401-405, 430-438
I.D. AM-Birth: maternal deaths (all), congenital cardiovascular anomalies, perinatal deaths (excluding stillbirths)	O00-O99, Q20-Q28, P00-P96	630-676, 745-747, 760-779
I.E. AM-Other: disease of thyroid, epilepsy, peptic ulcer, appendicitis, abdominal hernia, cholelithiasis & cholecystitis, nephritis, benign prostatic hyperplasia, misadventures to patients during surgical or medical care, cisticerchosis	E00-E07, 40-G41, K25-K27, K35-K38, K40-K46, K80-K81, N00-N07, N17-N19, N25-N27, N40, Y60-Y69, Y83-Y84, B69	240-246, 345, 531-533, 540-543, 550-553, 574-575.1, 580-589, 600, E870-E876, E878-E879
II. Diabetes	E10-E14	250
III. Ischemic Heart Diseases (IHD)	I20-I25	410-414, 429.2
IV. Lung cancer	C33-C34	162
V. Cirrhosis	K70	571.1-571.3
VI. Homicides	X85-Y09	E960-E969
VII. Road traffic accidents	V01-V99	E810-E819
VIII. Suicide and self-inflicted injuries	E950-E959	X60-X84, Y87.0
IX. Residual Causes : HIV/AIDS; other cancers and other heart diseases	B20-B24, U03; C00-D48; I00-I99 if not listed above; R00-R99	042-044;140-239; 390-459 if not listed above; 780-799

Temporary Life Expectancy

Temporary life expectancy between ages x_1 and x_2, for $x_1 < x_2$, is defined as the average years of life lived between these ages according to a given set of mortality rates (Arriaga 1984). We denote this quantity as ${}_{(x_2-x_1)}e_{x_1}$, and its benchmark based on minimum death rates for every age and cause of death among the Mexican states for each year as ${}_{(x_2-x_1)}e^{\star}_{x_1}$. Defined in terms of the lifetable survival function, $\ell(x)$:

$$ {}_{(x_2-x_1)}e_{x_1} = \frac{\int_{x_1}^{x_2} \ell(x)\ \mathrm{d}x}{\ell(x_1)} \tag{1} $$

If full survival is achieved, the life expectancy is $x_2 - x_1$. For example, if we set $x_1 = 0$ and $x_2 = 15$, and no person dies between the ages 0 and 15, on average the population lives 15 full years.

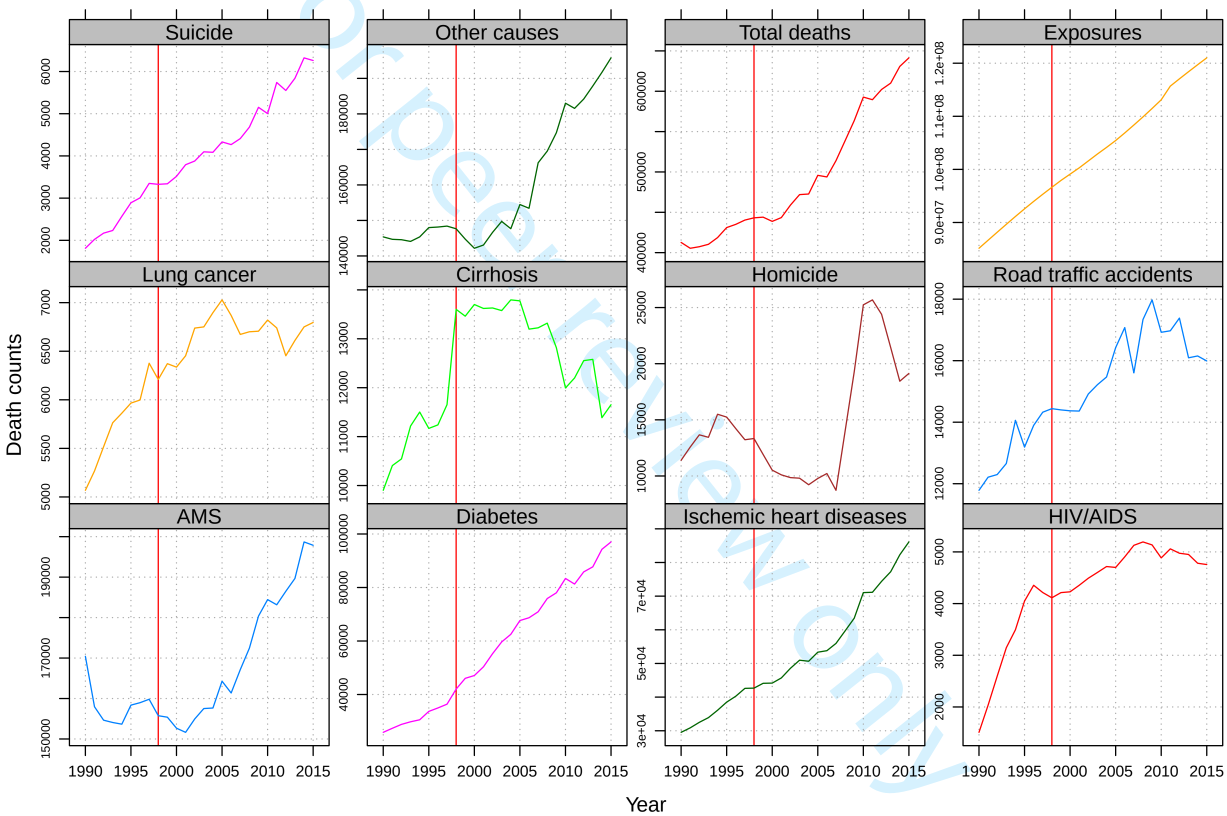
Decomposition method

The decomposition method used in this paper relies on a model of demographic functions based on continuous change (Horiuchi et al. 2008). Suppose P (e.g. temporary life expectancy between ages 15 and 49) is a differentiable function of n covariates (e.g. each age-cause specific mortality rate) denoted by the vector $\boldsymbol{A} = [x_1, x_2, \ldots, x_n]^T$. We assume that $\boldsymbol{A}$ is a differentiable function between P_1 and P_2, then the difference in P between P_1 and P_2 can be expressed as follows:

$$ P_2 - P_1 = \sum_{i=1}^{n} \int_{x_i(P_1)}^{x_i(P_2)} \frac{\partial P}{\partial x_i} dx_i = \sum_{i=1}^{n} c_i, \tag{2} $$

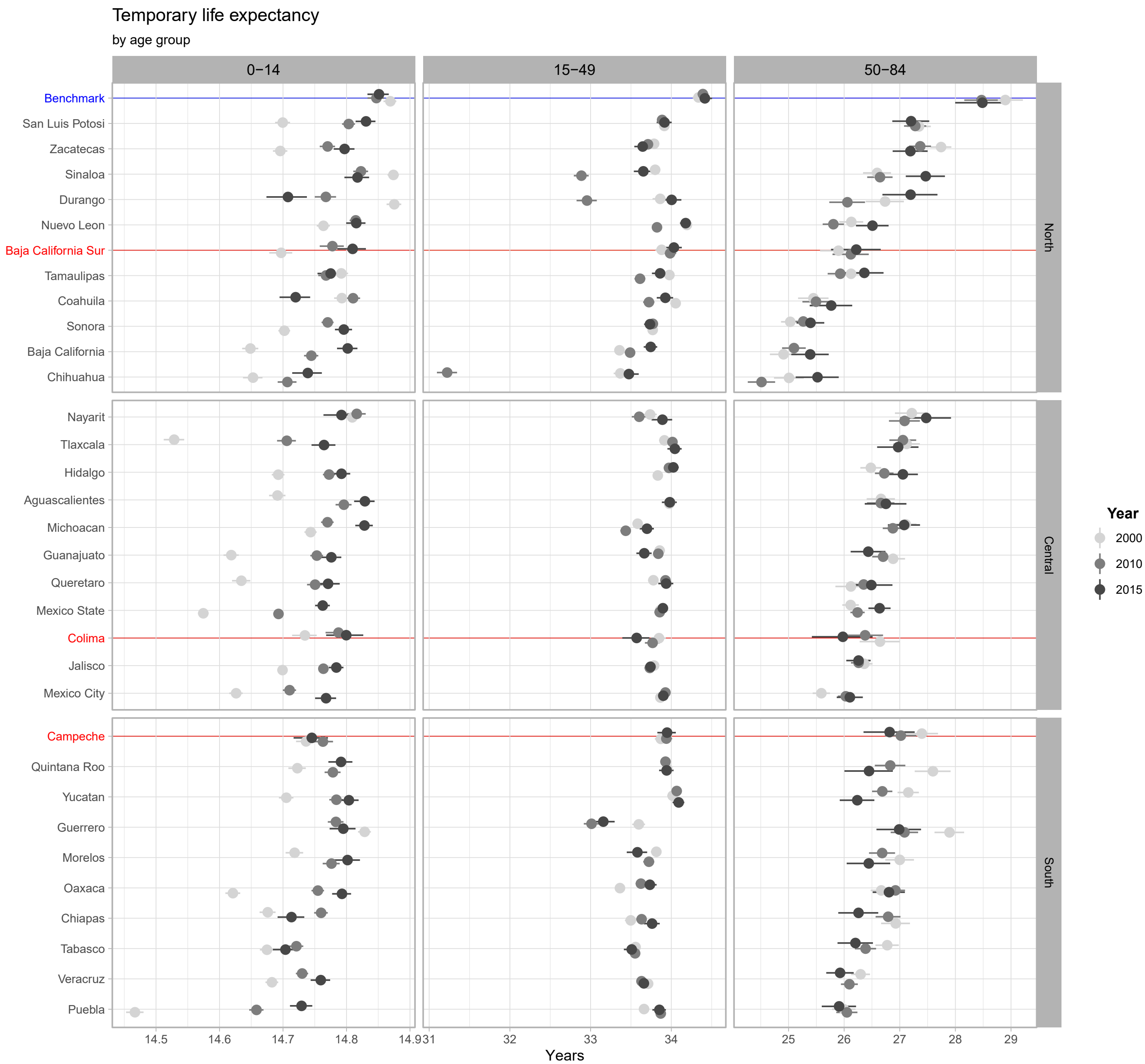
where c_i is the total change in P produced by changes in the i-th covariate, x_i. The c_i's in equation (2) were computed by numerical integration following the algorithm suggested by Horiuchi et al. (2008). This method has the advantage of assuming that covariates change gradually along the time dimension.

Figure 1: Cause-specific death counts (different y-scale for each cause), 1990-2010.



Note: AMS "amenable to medical service". The red line indicates the change from ICD 9 to ICD 10.

Robustness check: 95% CIs for male temporary life expectancies



Note: States highlighted in red had less than 1 million population in 2010.

References

Arriaga, E. E. (1984). Measuring and explaining the change in life expectancies. *Demography*, 21(1):83–96.

Horiuchi, S., Wilmoth, J. R., and Pletcher, S. D. (2008). A decomposition method based on a model of continuous change. *Demography*, 45(4):785–801.

Figure 2: Inequality in life expectancy between states for youngest (0-14), young adults (15-49), and older adults (50-84) by sex, 1990-2015.

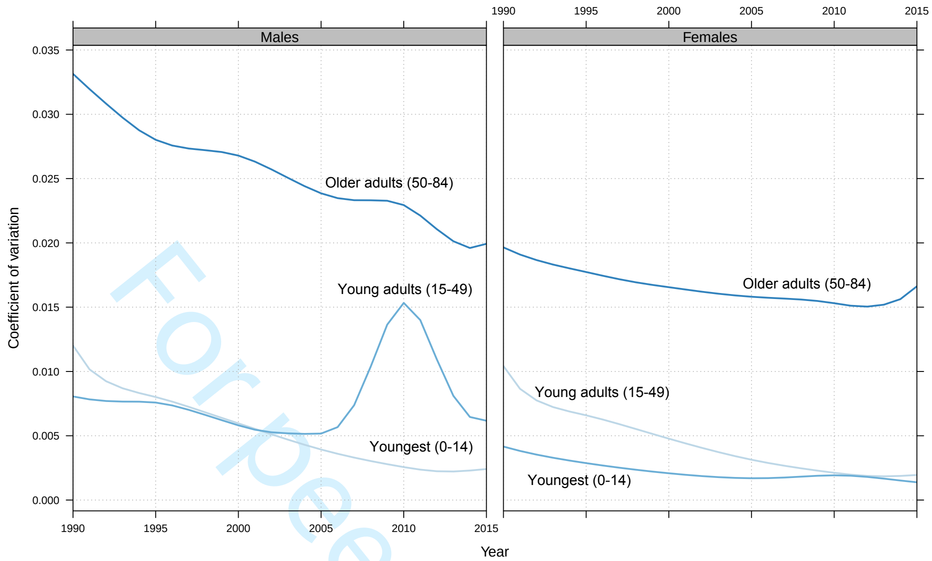
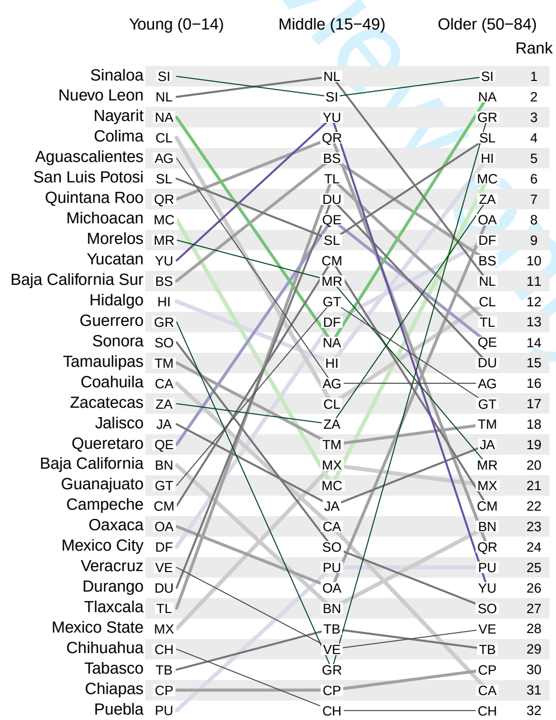
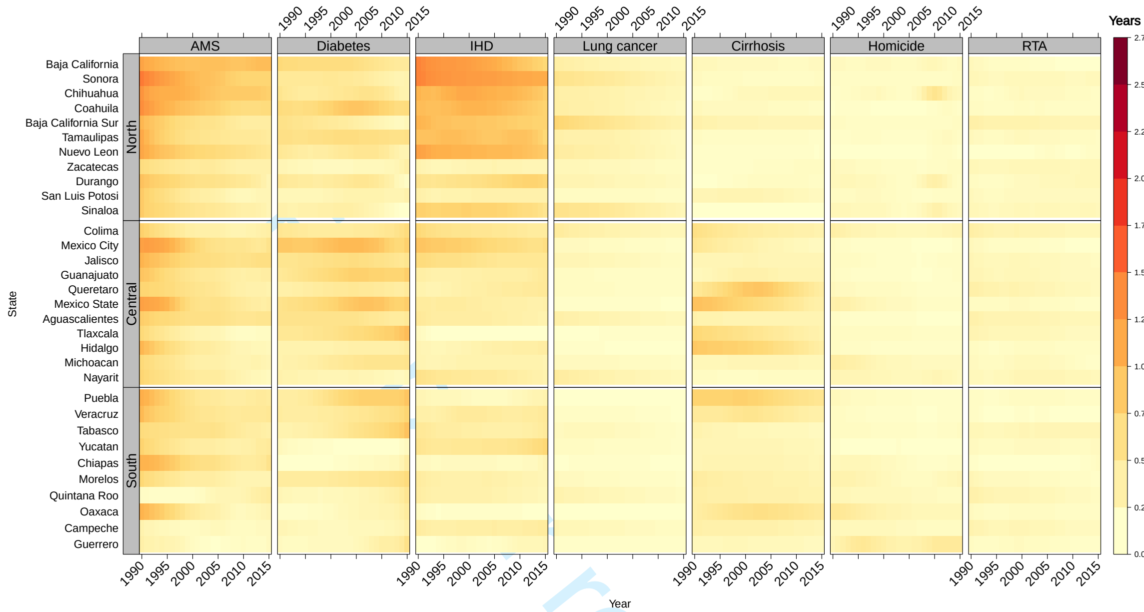


Figure 3: State ranking for average female life expectancy 2010-15 for the youngest (0-14), young adults (15-49), and older adults (50-84).



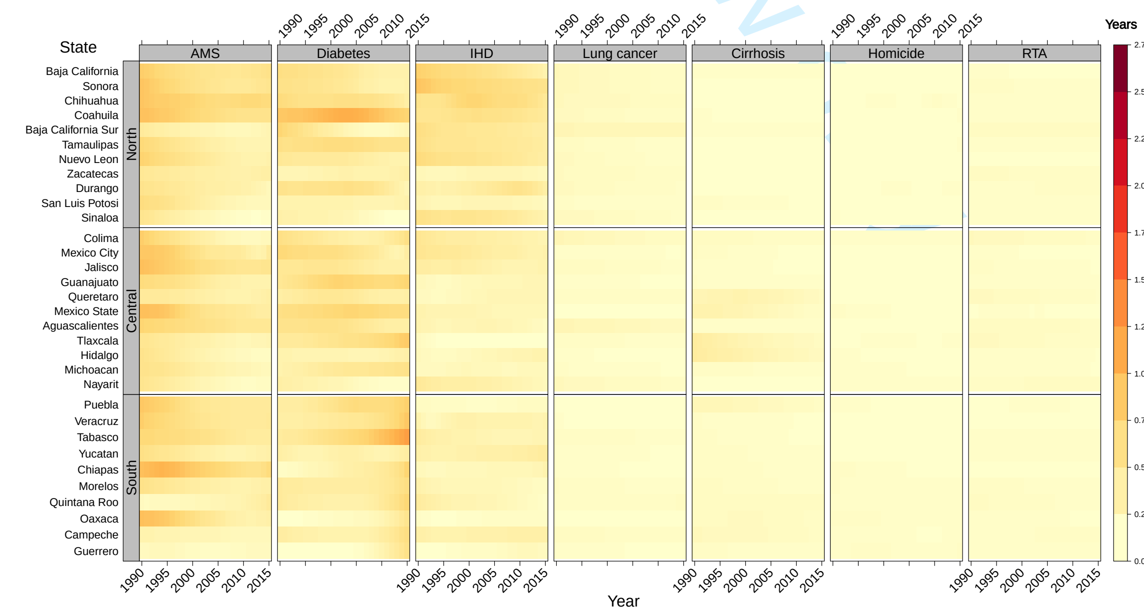
Source: calculations based on INEGI and CONAPO files.

Figure 4: Cause-specific contributions to state differences from low mortality benchmark for older male adults (ages 50-84), 1990-2015. States grouped into three regions. Reproduced from manuscript Figure 4 to have color scale comparable with other Supplementary figures. In subsequent figures 5-9 the color was rescaled to make them comparable over age groups in the supplemental material, the maximum value observed was 2.6 years caused by homicides in Chihuahua in 2010.



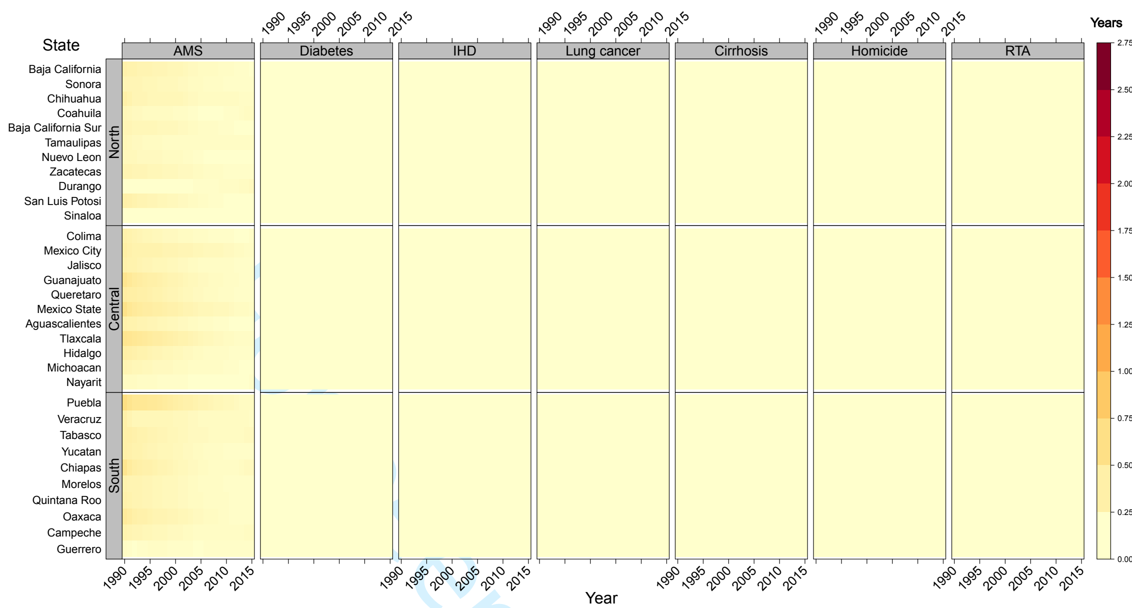
Note: AMS is "amenable to medical service", IHD is "isquemic heart diseases", and RTA is "road traffic accidents". Source: own calculations.

Figure 5: Cause-specific contributions to state differences from low mortality benchmark for older female adults (ages 50-84), 1990-2015.



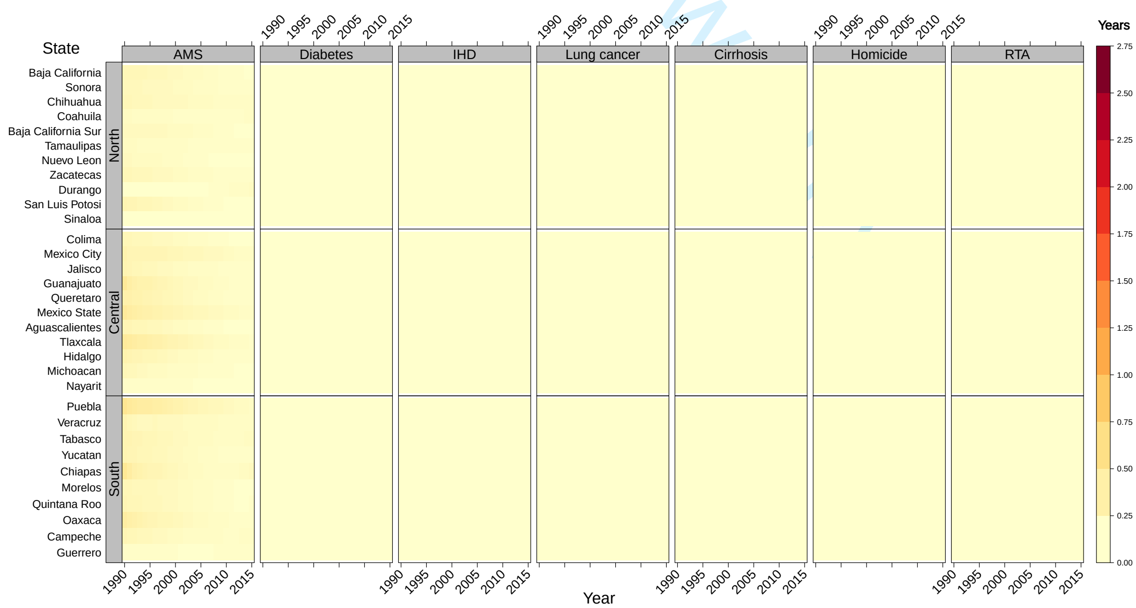
Note: AMS is "amenable to medical service", IHD is "isquemic heart diseases", and RTA is "road traffic accidents". Source: own calculations.

Figure 6: Cause-specific contributions to state differences from low mortality benchmark for male youngest population (ages 0-14), 1990-2015.



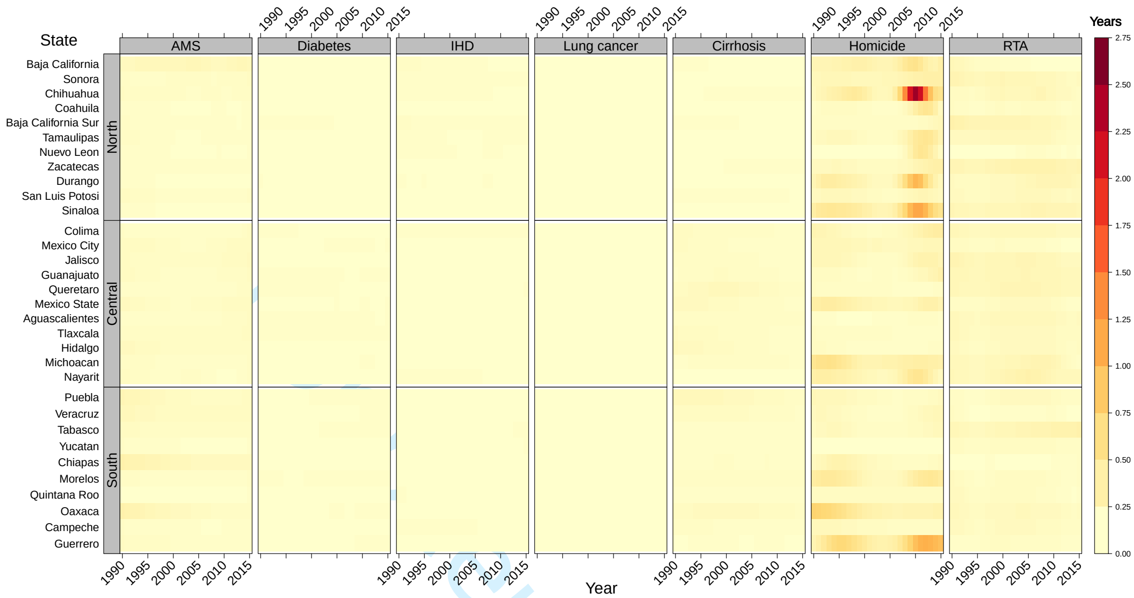
Note: AMS is "amenable to medical service", IHD is "isquemic heart diseases", and RTA is "road traffic accidents". Source: own calculations.

Figure 7: Cause-specific contributions to state differences from low mortality benchmark for female youngest population (ages 0-14), 1990-2015.



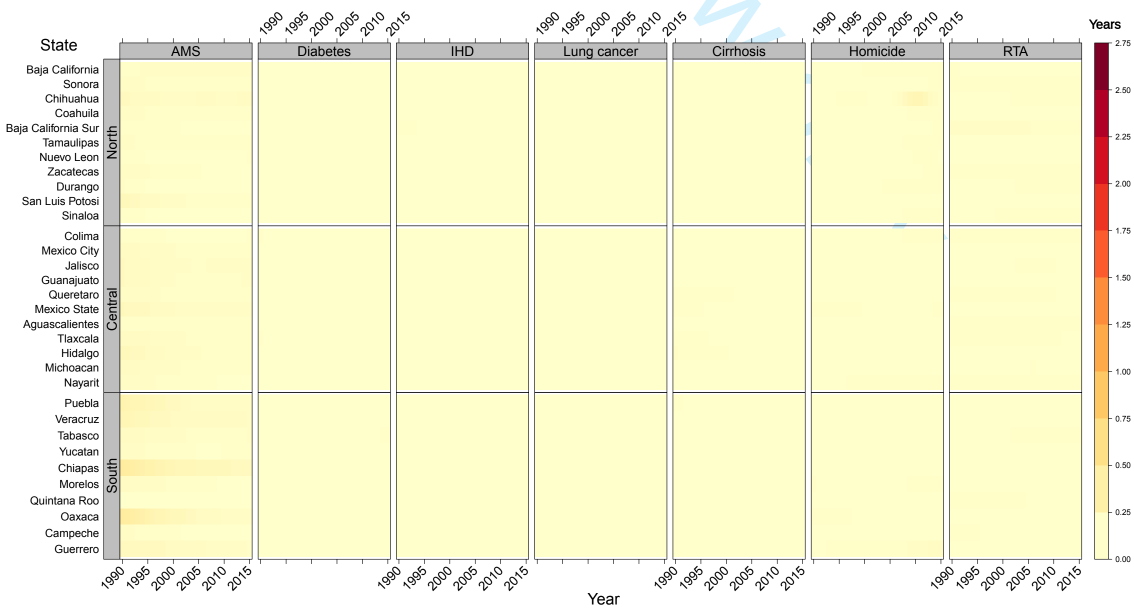
Note: AMS is "amenable to medical service", IHD is "isquemic heart diseases", and RTA is "road traffic accidents". Source: own calculations.

Figure 8: Cause-specific contributions to state differences from low mortality benchmark for male young adults (ages 15-49), 1990-2015.



Note: AMS is "amenable to medical service", IHD is "isquemic heart diseases", and RTA is "road traffic accidents". Source: own calculations.

Figure 9: Cause-specific contributions to state differences from low mortality benchmark for female young adults (ages 15-49), 1990-2015.



Note: AMS is "amenable to medical service", IHD is "isquemic heart diseases", and RTA is "road traffic accidents". Source: own calculations.

Figure 10: State specific gap with low mortality benchmark for selected years between ages 0-14. Source: own calculations.

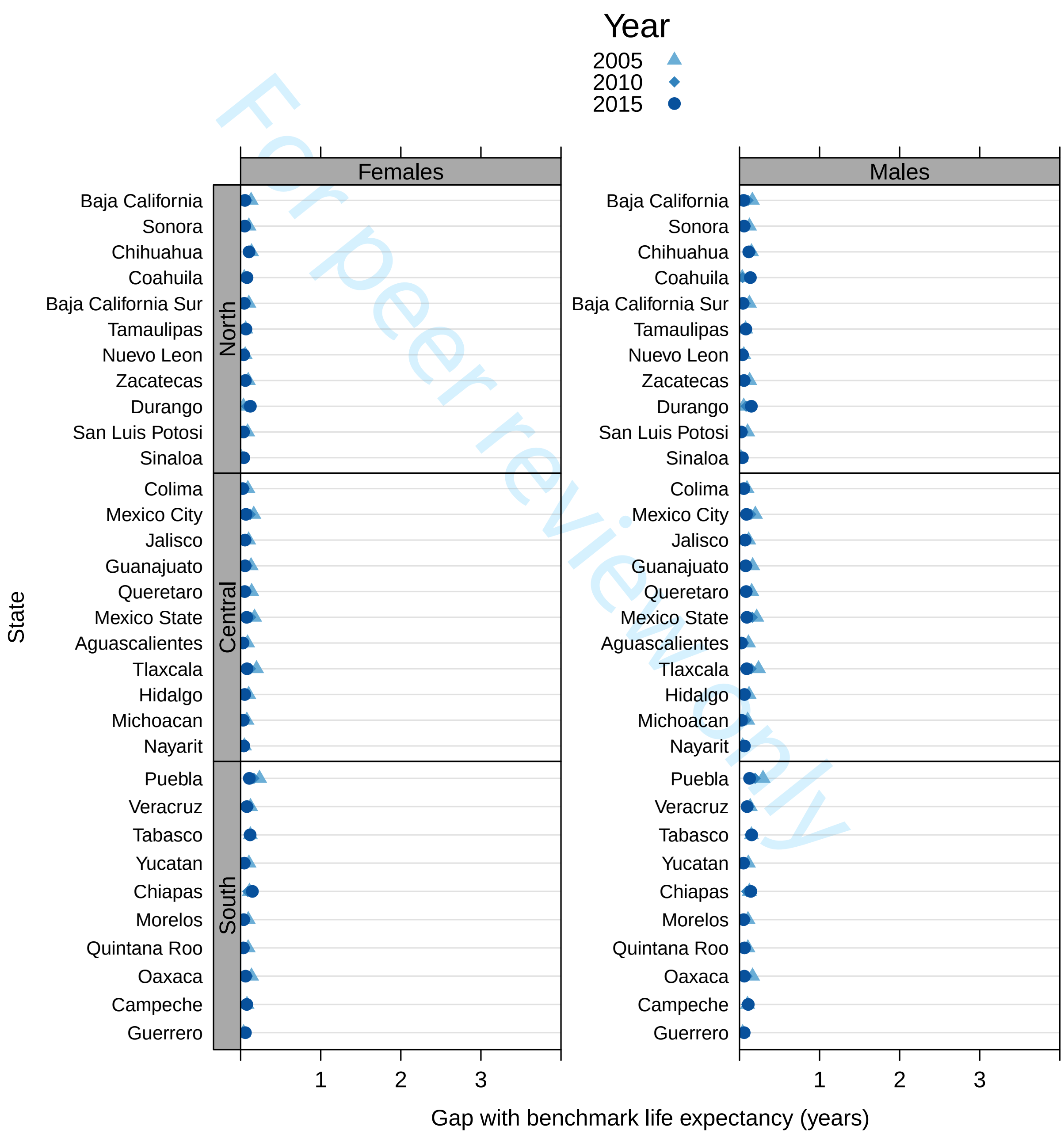


Figure 11: State specific gap with low mortality benchmark for selected years between ages 15-49. Source: own calculations.

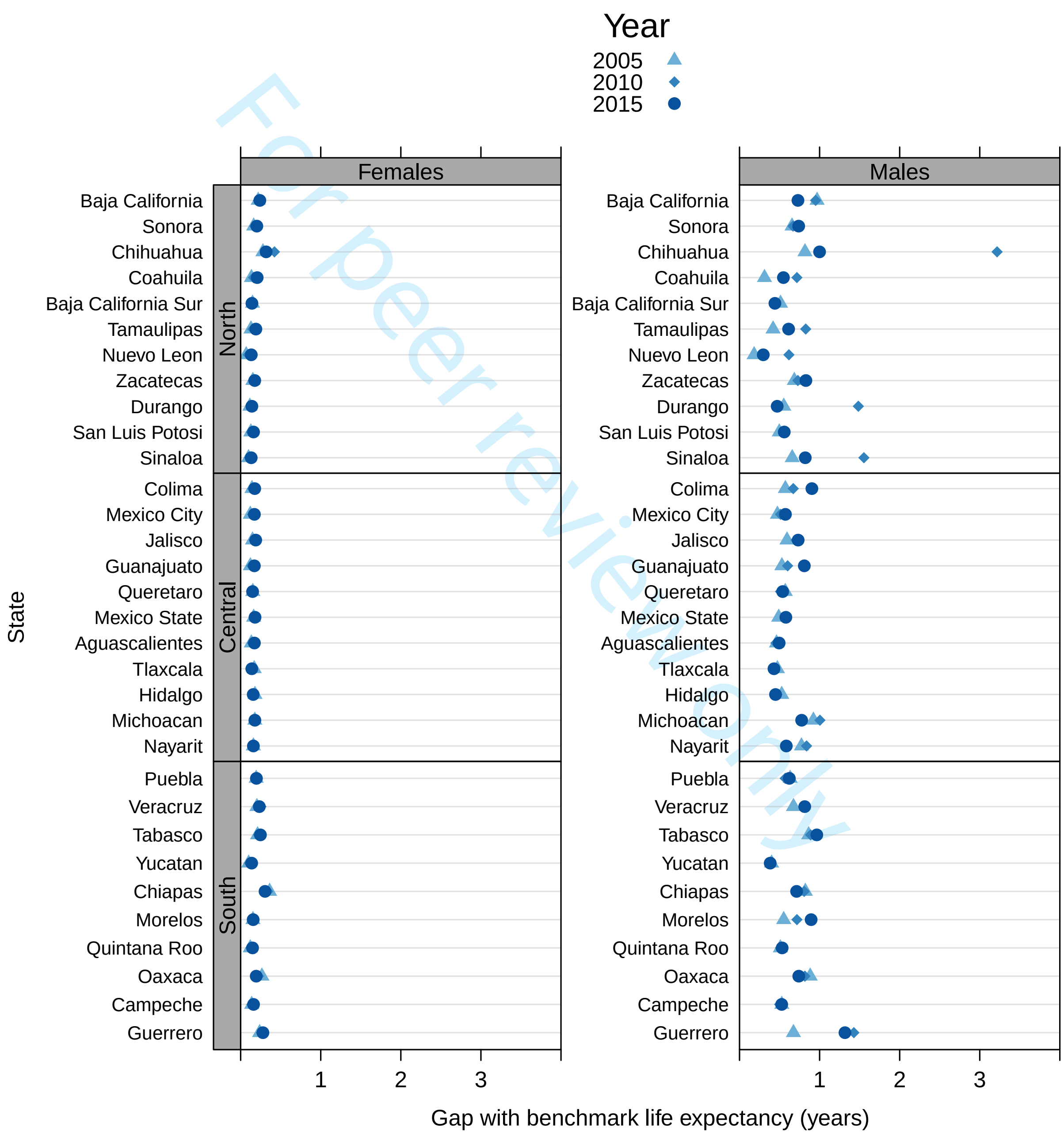


Figure 12: State specific gap with low mortality benchmark for selected years between ages 50-84. Source: own calculations.

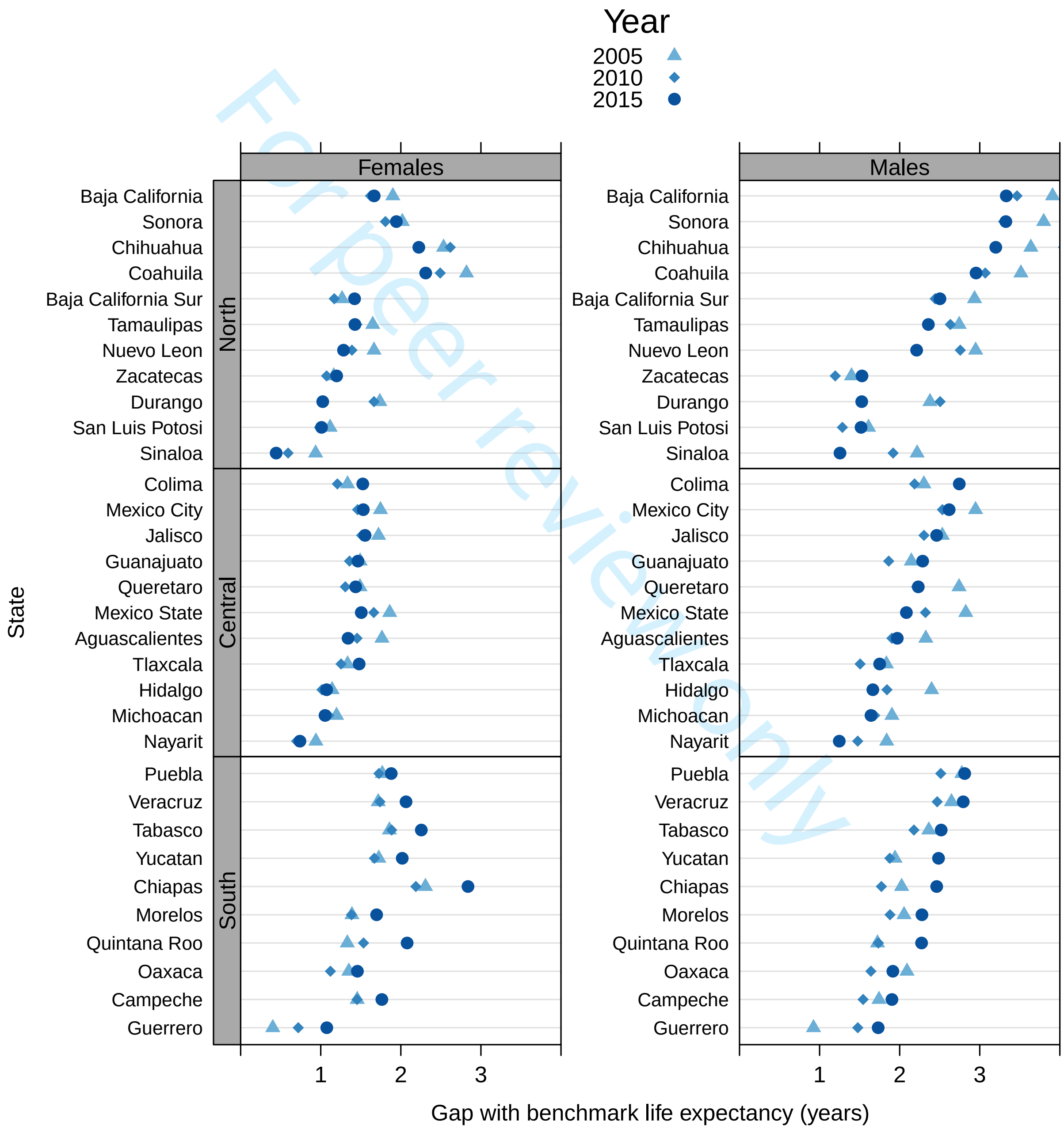


Figure 13: Proportion by cause of death from benchmark mortality for youngest females (ages 0-14). Source: own calculations.

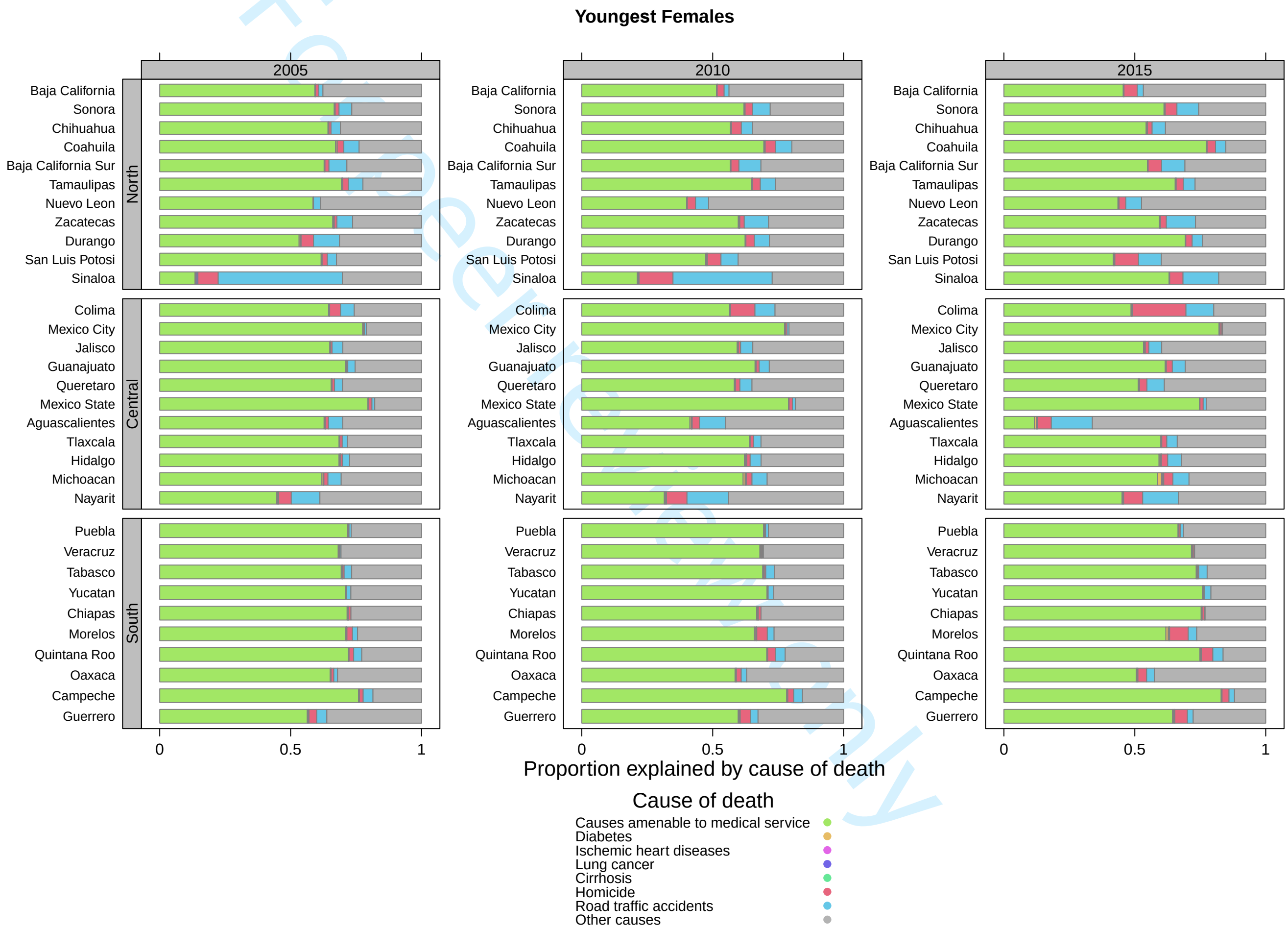


Figure 14: Proportion by cause of death from benchmark mortality for youngest males (ages 0-14). Source: own calculations.

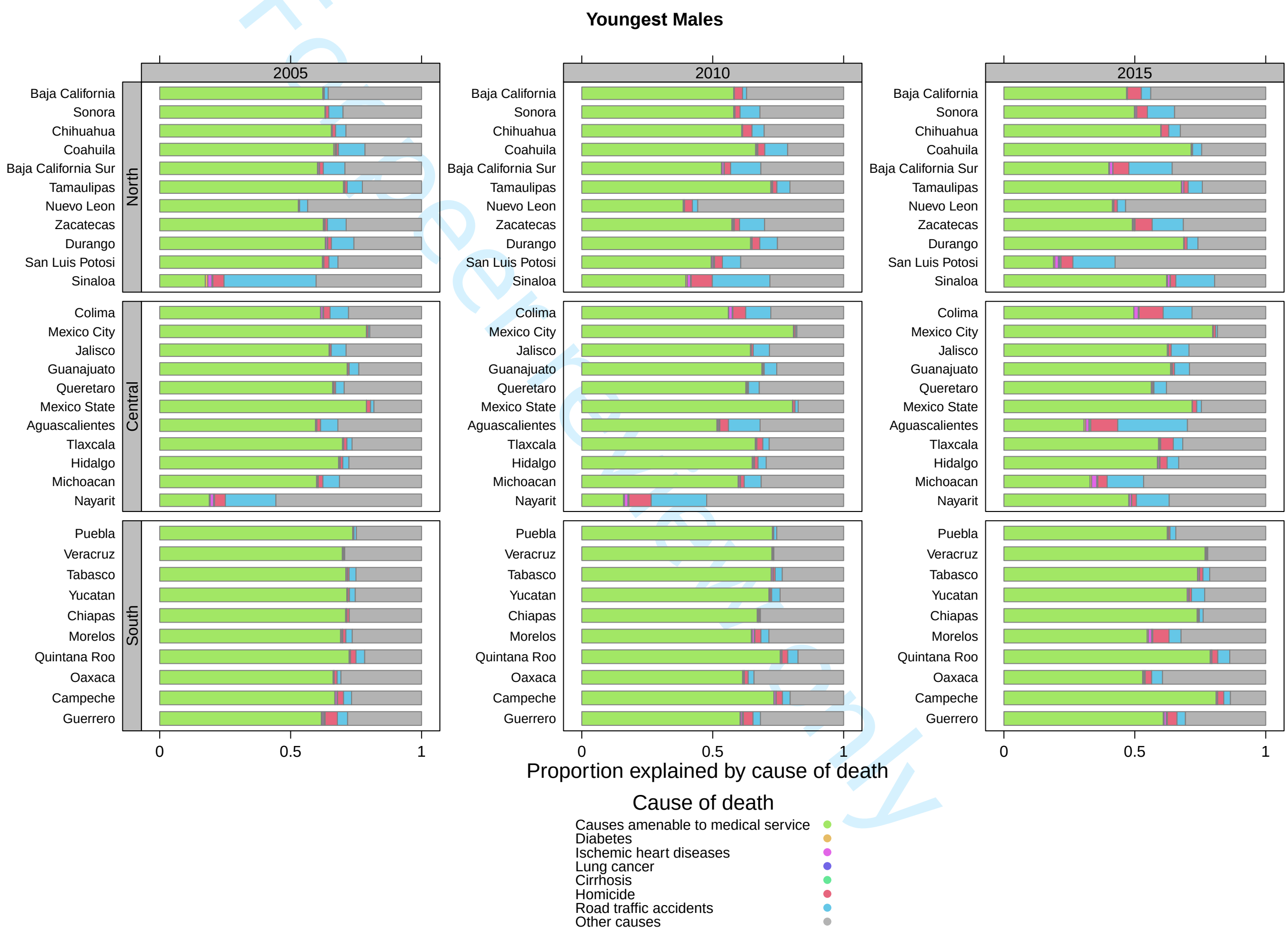


Figure 15: Proportion by cause of death from benchmark mortality for young adult females (ages 15-49). Source: own calculations.

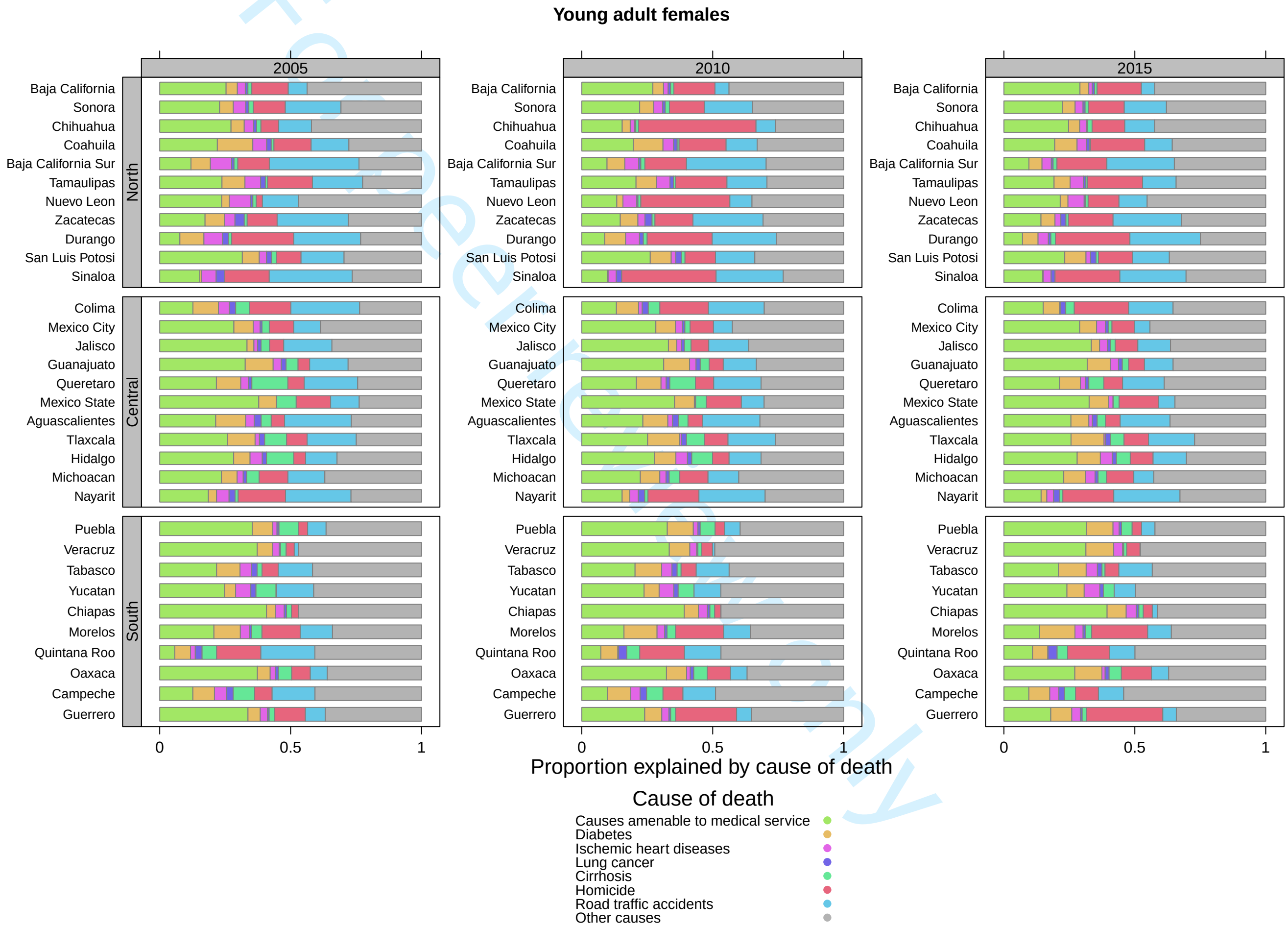


Figure 16: Proportion by cause of death from benchmark mortality for young adult males (ages 15-49). Source: own calculations.

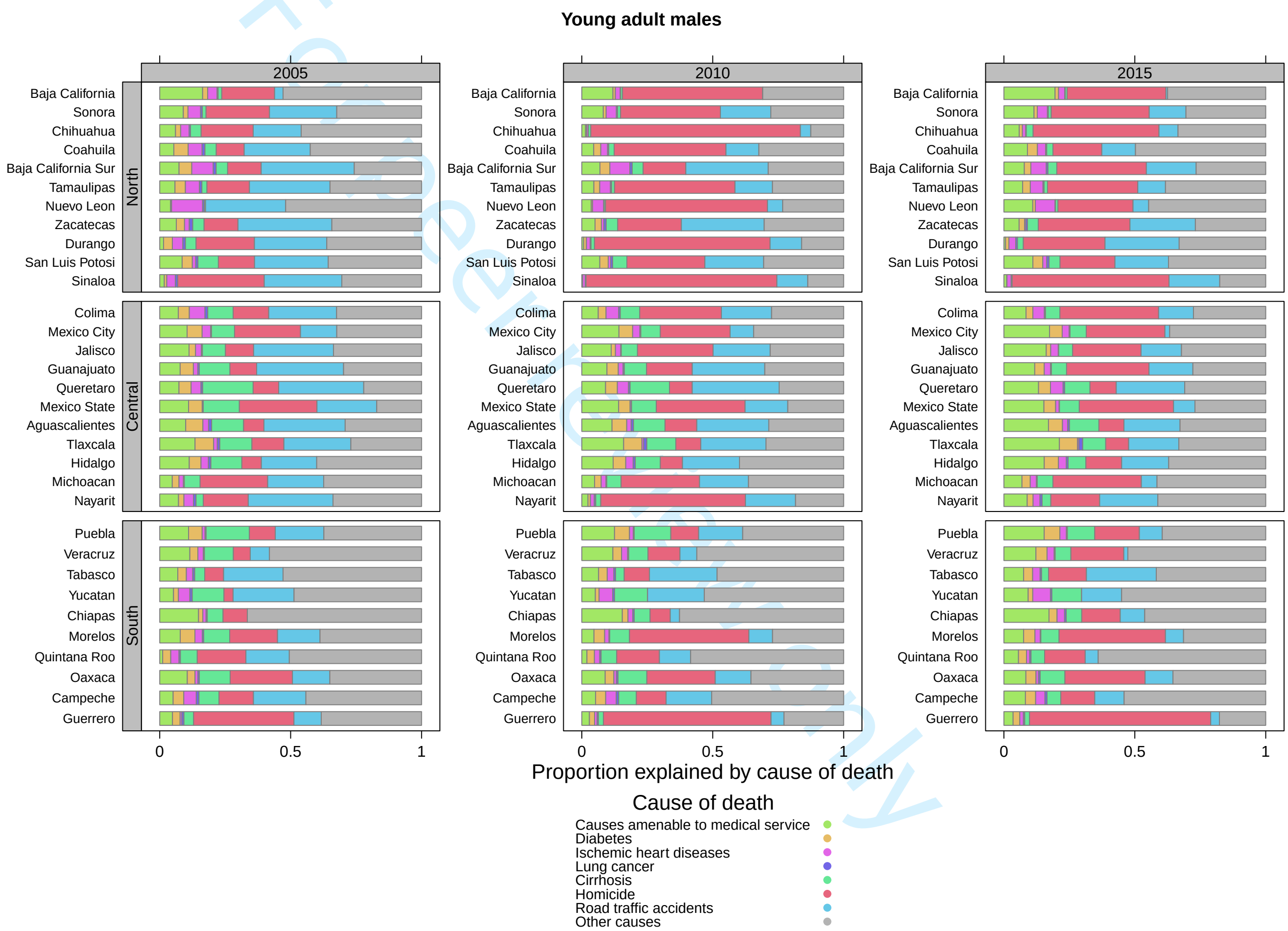


Figure 17: Proportion by cause of death from benchmark mortality for older male adults (ages 50-84). Source: own calculations.

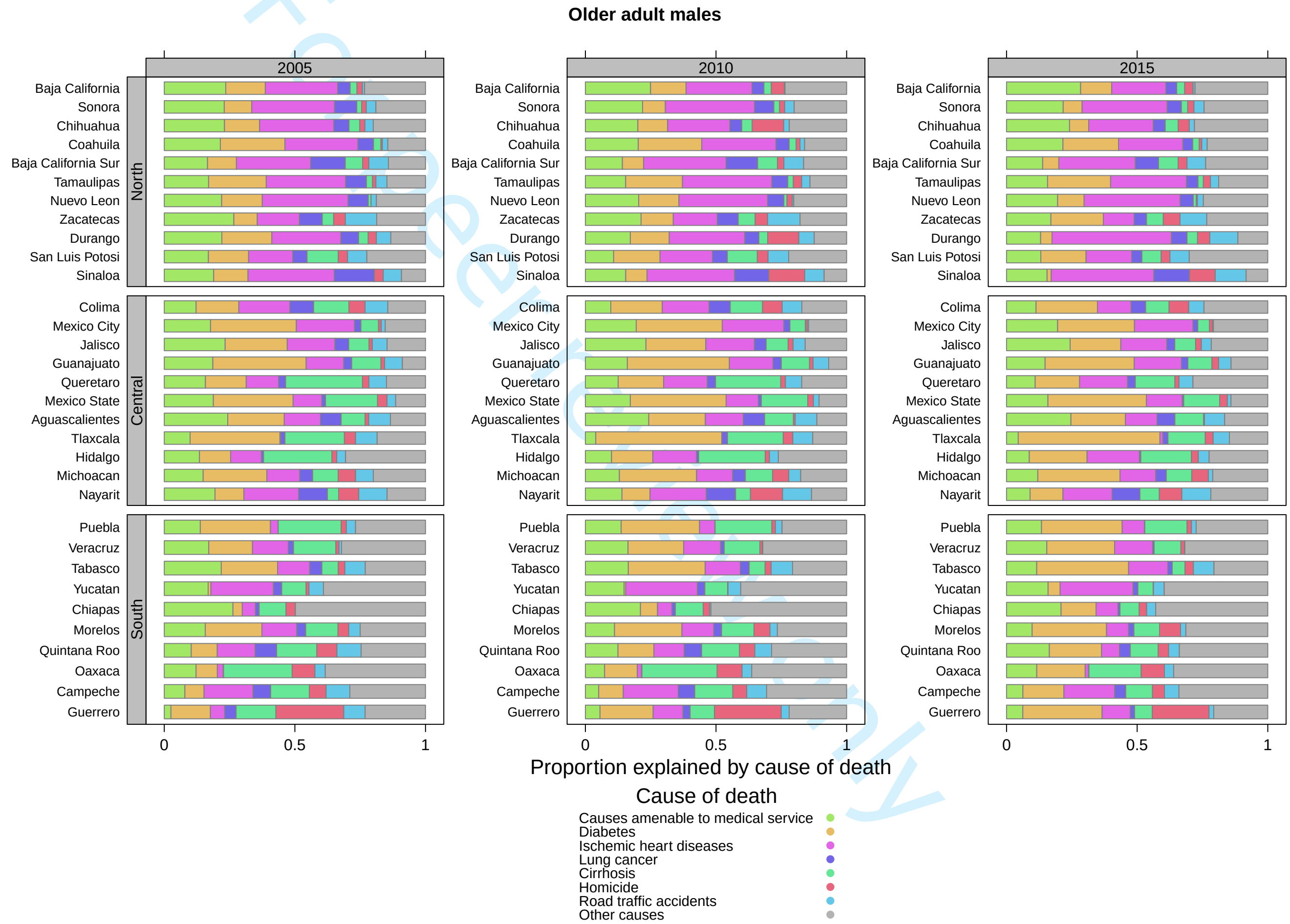
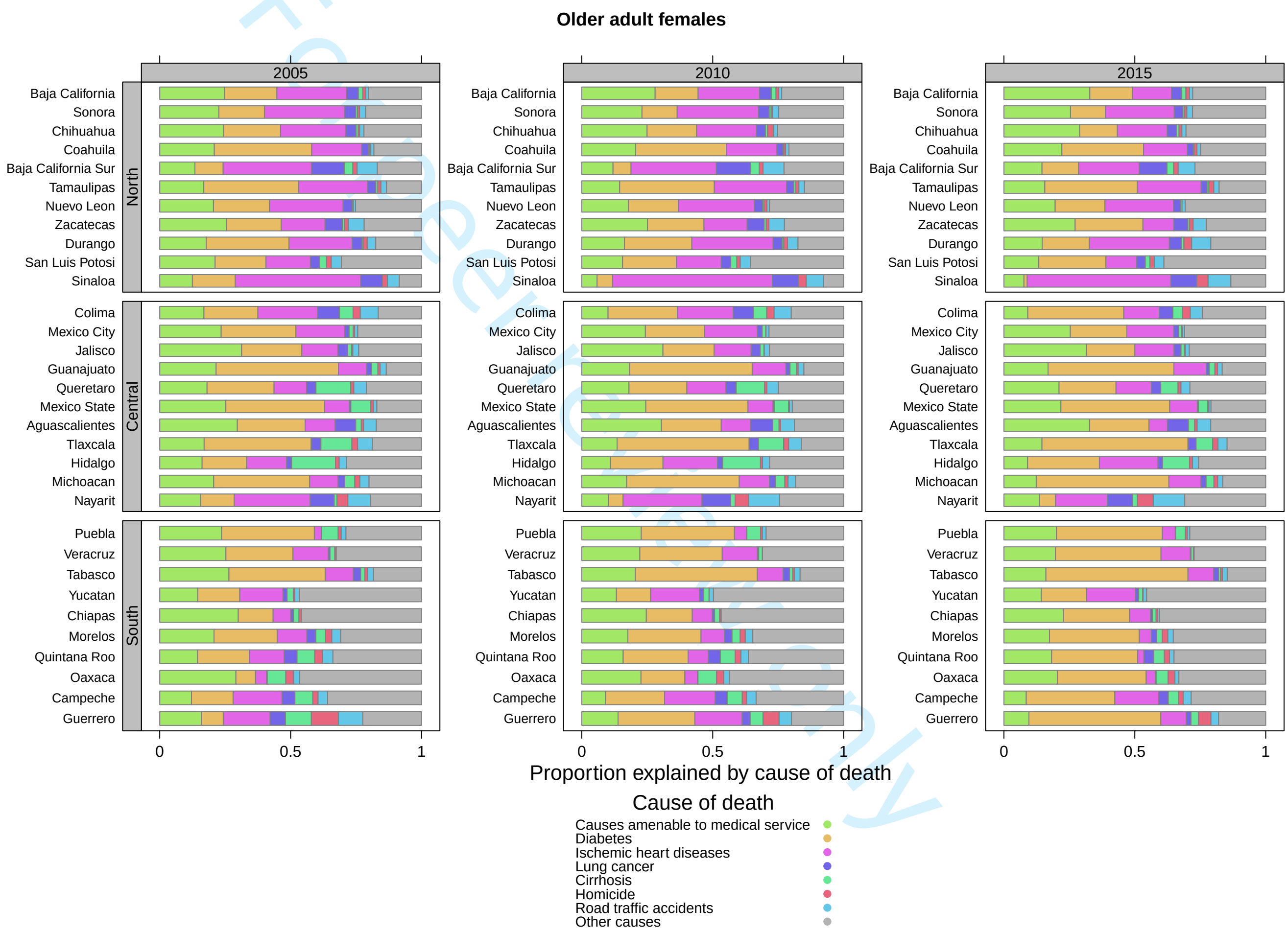


Figure 18: Proportion by cause of death from benchmark mortality for older female adults (ages 50-84). Source: own calculations.



STROBE Statement—Checklist of items that should be included in reports of ***cross-sectional studies***

	Item No	Recommendation
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract **(done)**
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found **(done)**
Introduction		
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported **(done)**
Objectives	3	State specific objectives, including any prespecified hypotheses **(done)**
Methods		
Study design	4	Present key elements of study design early in the paper **(done)**
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection **(done)**
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants **(done)**
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable **(done)**
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group **(done)**
Bias	9	Describe any efforts to address potential sources of bias **(done)**
Study size	10	Explain how the study size was arrived at **(done)**
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why **(done)**
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding **(done)**
		(*b*) Describe any methods used to examine subgroups and interactions **(done)**
		(*c*) Explain how missing data were addressed (Not applicable [NA])
		(*d*) If applicable, describe analytical methods taking account of sampling strategy (NA)
		(*e*) Describe any sensitivity analyses **(done)**
Results		
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed (**Target population defined)**
		(b) Give reasons for non-participation at each stage
		(c) Consider use of a flow diagram
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders **(done)**
		(b) Indicate number of participants with missing data for each variable of interest **(NA)**
Outcome data	15*	Report numbers of outcome events or summary measures **(done)**
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included **(done)**

		(*b*) Report category boundaries when continuous variables were categorized **(NA)**
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period **(NA)**
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses **(done)**
Discussion		
Key results	18	Summarise key results with reference to study objectives **(done)**
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias **(done)**
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence **(done)**
Generalisability	21	Discuss the generalisability (external validity) of the study results **(done)**
Other information		
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based **(NA)**

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

Trends in avoidable mortality over the life course in Mexico, 1990-2015: A cross-sectional demographic analysis

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Complete List of Authors:	Aburto, José Manuel; Syddansk Universitet Det Sundhedsvidenskabelige Fakultet, Biodemography Unit, Department of Public Health; Max-Planck-Institut fur Demografische Forschung, Lifespan Inequalities Research group Riffe, Tim; Max-Planck-Institut fur Demografische Forschung Canudas-Romo, Vladimir; Australian National University College of Arts and Social Sciences
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Title: Trends in avoidable mortality over the life course in Mexico, 1990-2015: A cross-sectional demographic analysis

Authors: José Manuel Aburto, *PhD student* (JMA)[a,b*†], Tim Riffe, *Research Scientist* (TR)[b†] & Vladimir Canudas-Romo, *Associate Professor* (VCR)[c]

Author affiliations:

[a] Center on Population Dynamics (CPop), University of Southern Denmark, Odense 5000, Denmark.

[b] Max Planck Institute for Demographic Research, Rostock 18057, Germany

[c] School of Demography, Australian National University, ACT 0200, Australia

[†] These authors contributed equally to the paper

[*]The manuscript's guarantor.

Corresponding author: José Manuel Aburto: jmaburto@health.sdu.dk, T: +45 65509416

Keywords health inequalities, adult health, amenable mortality, violence, homicides

Abstract

Objective: To analyse average lifespan and quantify the effect of Avoidable/Amenable mortality on the difference between state-specific mortality and a low-mortality benchmark in Mexico during 1990-2015.
Design: Retrospective cross-sectional demographic analysis using aggregated data.
Setting: Vital statistics from the Mexican civil registration system.
Participants: Aggregated national data (from 91.2 million people in 1995 to 119.9 in 2015) grouped in 64 populations (32 Mexican-states [including Mexico City] by sex) with cause-of-death data.
Main outcome measures: Cause-specific contributions to the gap in life expectancy with a low-mortality benchmark in three age groups (0-14, 15-49 and 50-84).
Results: Infants and children under age 15 show improvements towards maximal survival in all states. However, adult males aged 15 to 49 show deterioration after 2006 in almost every state due to increasing homicides, and a slow recovery thereafter. Out of 35 potential years, females and males live on average 34.57 (34.48 to 34.67) and 33.80 (33.34 to 34.27), respectively. Adults aged 50 to 84 show an unexpected decrease in the low mortality benchmark, indicating nation-wide deterioration among older adults. Females and males in this age group show an average survival of 28.59 (27.43 to 29.75) and 26.52 (25.33 to 27.73) out of 35 potential years, respectively. State gaps from the benchmark were mainly caused by ischemic heart diseases, diabetes, cirrhosis and homicides. We find large health disparities between states, particularly for the adult population after 2005.
Conclusions: Mexico has succeeded in reducing mortality and between-state inequalities in children. However, adults are becoming vulnerable as they have not been able to reduce the burden of violence and conditions amenable to health services and behaviours, such as diabetes, ischemic heart diseases and cirrhosis. These trends have led to large health disparities between Mexican states in the last 25 years.

Strengths and limitations of this study

- We analyse nine cause-of-death groups using the concept of avoidable/amenable mortality, which enables us to capture recent changes in mortality in Mexico.
- We introduce a methodology to quantify the impact of medically amenable mortality and behavior related conditions on life expectancy relative to a low mortality benchmark.
- We analyze patterns in life expectancy for different age groups over time (1995-2015) and simultaneously account for changes in causes of death and inequality between states that have undergone major social and public health transitions.
- Mortality data from Mexico are likely to present inaccuracies in cause-of-death classification due to comorbidities, particularly at older ages.
- Our estimates of homicide mortality are likely to be underestimated due to inaccurate practices in counting and reporting, and due to the large number of missing individuals in Mexico

Introduction

The second half of the 20th century was marked by sizable improvements in mortality, living conditions, and health in most Latin American countries.[1] In Mexico, these improvements have slowed down recently due to opposing trends in particular causes of death. For instance, homicide and diabetes increased during the first decade of the 2000's, even as infectious and respiratory diseases continued to fall over the same period. While life expectancy at birth increased by 4.3 years for males (from 67.6 to 71.9) and 3.4 years for females (from 73.8 to 77.2) between 1990 and 2000,[2] between 2000 and 2010, life expectancy at birth entered into a period of stagnation for males and slowed progress for females.[3]

This period coincides with ongoing public health interventions, such as the Universal Vaccination Program and established health systems (IMSS, ISSSTE), and with the implementation of a Universal Health Coverage program (*Seguro Popular*). The latter program provides primary and secondary health care to the uninsured population and distributes funds to cover catastrophic health expenditures.[4] Further, since 1997 conditional cash transfer programs were introduced to supply incentives for poor families to invest in education, health, and nutrition.[5] Some evidence suggests that Mexico experienced substantial decreases in infant and child mortality, and in the prevalence of acute malnutrition between 1980 and 2000 thanks in part to these interventions.[6] Similarly, by 2012 *Seguro Popular* had provided health insurance coverage to an additional 52 million people in Mexico (or 44.4% of the population), leading to increased access to public health care and protection from the financial consequences of disease.[7]

Conditional cash transfers have focused on the poorest states, and *Seguro Popular* was introduced at different times in different states across the country. Although these actions underscore broad progress in public health interventions, they mask disparities between Mexican states and epidemiological patterns that differ between age groups. For instance, Mexico faces a rapid aging process in which an interaction between infectious diseases and noncommunicable conditions can be anticipated in the adult population[i].[8] Therefore, it is necessary to assess the varied impacts that these interventions may have had on mortality in Mexican states at different ages.[9]

One approach to approximate the impact of health care and other interventions on survival, and to reveal potential areas of improvement is by operationalizing the concept of Avoidable or Amenable Mortality (hereafter abbreviated AM).[10 11]This categorization of mortality aims to measure the quality of health service systems by selecting certain causes of death that should not occur in the presence of effective and timely health care. Therefore, improvements in AM mortality are expected over time, as has been observed in several countries. For example, among 19 industrialized countries, including 14 countries from Western Europe, USA, Canada, Australia, New Zealand and Japan, a reduction in AM rates was observed over the past 20 years.[10] Avoidable mortality rates fell, on average, by 17% for males and 14% for females in these countries between 1997 and 2003. The USA lagged behind the other countries in this group, while Japan, France, and Australia were the top performers. Despite mortality reductions from cancers and circulatory diseases for both sexes, disparities between countries persist, with the United States showing the smallest reductions (around 5%) for both sexes.[10]

In Mexico, the components of avoidable mortality have undergone opposing trends since the late 1990's. Mortality from infectious diseases and nutrition-related conditions decreased between 2000 and 2004,[12] while deaths related to diabetes and ischemic heart diseases increased in the first decade of the 2000s.[13] Importantly, increases in the latter causes of death were concentrated in the poorest states of the country.[13]

The objective of this research is twofold. First, we analyse trends in average lifespan for all 32 Mexican states, by sex, and over the full period from 1990 to 2015. This extends previous studies that focused on the 21st century.[3 13-16] Our study period covers several public health interventions and captures several major trends in state and cause-of-death variation. Second, we further segment AM into health intervention-related and behaviour-related AM causes that best characterise the epidemiological patterns of Mexico[14] This lets us quantify the effect of the components of AM on the difference between state mortality levels and an easy-to-understand low-mortality benchmark calculated for large age groups (i.e. 0-14, 15-49 and 50-84). This benchmark concept has been previously used in mortality studies.[17-19] Deviations from the low-mortality benchmark indicate a strong potential for improvement.

We hypothesize age-dependent variations in mortality outcomes. In particular, since public health interventions are mainly focused on infant and child health, we expect convergence between states and improvement in survival for infants and children aged 0 to 15. For instance, the vaccination program and *Seguro Popular* aim to cover all children, and recent evidence suggests a decrease in mortality below age 15 due to a decline in infectious and respiratory diseases.[20] On the contrary, we expect little improvement in survival for the young-adult population (ages 15 to 35) due to the sudden and egregious rise in homicide mortality.[21] We foresee health deterioration among older adults due to documented increases in diabetes mortality.[20] Although every state has the commitment to provide universal coverage and equitable access to health care, we anticipate disparities in mortality improvements between states due to heterogeneous epidemiological transitions among states,[16] and differences in the implementation and delivery of health care programs.[22]

Data sources & methods

Our analyses are based on publicly available anonymized datasets. We used 100% sample death register microdata files produced by the Mexican Statistical Office (INEGI) for years 1990 to 2015.[23] We aggregated individual deaths from these annual files by causes of death, single year of age, sex, and state of residence at the time of death. Population estimates from 1990 to 2015 were produced by the Mexican Population Council (CONAPO).[24] These population estimates adjust for age misstatement, undercounting, and interstate and international migration. Death counts and estimates of the population exposed to risk were used to calculate age and cause specific death rates by sex for each state from 1990 to 2015.

Classification of Causes of Death

To classify deaths we use the concept of "Avoidable/Amenable" Mortality (AM).[10 11] We group causes of death into nine categories based on recent classification adapted to the case of Mexico.[14] The first category refers to those conditions that are susceptible to medical intervention, such as infectious and respiratory diseases, some cancers and circulatory conditions, and birth conditions, among others. We label this category as "Causes amenable to medical service". We separate diabetes, ischemic heart diseases (IHD), lung cancer, and cirrhosis as subcategories of AM because these causes are susceptible to both health behaviour and medical service, and because the first two represent major causes of death among Mexican adults.[16] We also separate homicide, suicide and road traffic accidents because they have emerged as leading causes of death among young people, and the first one recently had a sizable impact on life expectancy in Mexico.[14] We grouped remaining causes into a single category labelled "Other causes".

Death data were originally classified according to the International Classification of Diseases (ICD), revision 9 for years 1990 to 1997 and revision 10 for 1998 to 2015 (see Additional file 1 Table 1 for details on ICD codes for each category). To check the validity of these cause-of-death codes in Mexico, we performed a sensitivity analysis and did not find major ruptures in mortality trends by AM classification (See Additional file 1, Figure 1).

Comorbidity in the old age population has increased in Mexico.[25] As a result inaccuracies may arise in cause of death registration due to problems associated with medical diagnosis, and selection and coding of the leading cause of death. Although analyses older ages should consider multiple causes of death to better represent old age mortality, we focus on the primary cause of death. We truncate our analysis at age 85 to avoid misinterpreting results related to inaccurate cause-of-death coding practices.

Age groups

We calculate life expectancy in three large age groups to capture mortality differences over the life course. Life expectancy in each age group refers to the average years of life lived between two ages conditional on survival to the lower age bound. This measure is also known in demographic analysis as temporary life expectancy.[26] The first age group contains infants and children aged 0-14. This group is likely to represent improvements in causes amenable to medical service (e.g. infectious diseases and conditions of the perinatal period).[3] The second group, aged 15-49, is used to capture the effect of homicide mortality and external causes historically related to the young-adult mortality hump, as well as maternal mortality for women.[27] This age group had an important impact on changes in state life expectancy in the first decade of the 2000s.[14] The third group covers older adults aged 50-84. Older adults are likely to represent a vulnerable group due to increases in non-communicable diseases and injury-related mortality in recent years.[16 28]

Low mortality benchmark

Our low-mortality benchmark is calculated on the basis of the lowest observed mortality rates over all states by age, year, cause, and sex. The resulting minimum mortality rate schedule has a unique age profile, and it determines our benchmark temporary life expectancy, which we calculate for our three age groups. This benchmark is a practical reference because it is based neither on a projection of improvements into the future nor on an arbitrary and likely dissimilar population. It can be treated as the best presently achievable mortality assuming perfect diffusion of the best available practices and technologies in Mexico.[19]

Methods

Cause-specific death rates underlie all indices reported in this work. To mitigate the impact of random variations over time and to correct for age-heaping, we adjust these rates in two steps. First, we smooth cause-specific rates over age and time for each state and sex separately using a 2-d p-spline.[29] Second, we rescale the smoothed cause-specific death rates to sum to the raw all-cause death rates for each sex and state. Period life tables up to age 84 for males and females from 1990 to 2015 and their benchmarks were calculated following standard demographic methods (for life table construction see Chapter 2 of reference 32).[30 31] We calculated temporary life expectancies [26](see Additional file 1 for a technical overview and 95% CIs) and estimated cause-specific contributions to the difference between each state and the low mortality benchmark using standard decomposition techniques.[32] The decomposition method used in this analysis is based on a model of demographic functions that change gradually over time.[32] It is a stepwise-based demographic method and has been successfully used to decompose age and cause-specific effects on life expectancy.[33] We provide a short description in the Supplemental Material and the results are fully reproducible from the R-code provided in the Data Sharing statement. Finally, to measure the level of disparity between states over time, we calculated the coefficient of variation of the gap between temporary life expectancy and the low mortality benchmark in each age group. This indicator is comparable over time and over age groups of different width. We also performed two-way ANOVA and post hoc tests to analyse disparities in temporary life expectancy between Mexican states and age groups.

Patient involvement

No patients were involved in setting the research question, outcome measures, or design of the study. No patients were asked to advise on the interpretation of the results and there are no plans on disseminating the results of this research to study participants or the relevant patient community.

Results

Trends in life expectancy for Mexican states by age-groups

Figure 1 presents temporary life expectancy by state for infants and children (ages 0-14), young adults (15-49) and older adults (50-84) over the period 1990-2015. Grey lines refer to each of the 32 states, black lines represent the state average, and the blue lines represent the low mortality benchmark. The black line at the top of each panel indicates the maximum liveable years in each age group: 15 for the youngest group, and 35 for young and older adults conditional on surviving to ages 15 and 50, respectively. Any gap between a state line and the blue line represents potential life expectancy gains if mortality were to drop to the low mortality benchmark.

All states show improvements in the youngest age group since 1990, approaching the low mortality benchmark, which itself is very close to maximum survival below age 15. This was observed even in the southern states such as Puebla, Chiapas and Tabasco which have lagged in reducing mortality in this age group throughout the entire period.

Male life expectancy between ages 15 and 49 showed a sudden drop after 2005 in almost every state in Mexico. In 2005, young males in this age group had a temporary life expectancy of 33.9 years (95% CI, 33.5 to 34.2) averaged over states. By 2010, the number of states below this level had increased from 14 to 23. Chihuahua, Sinaloa and Durango, in the northern region, experienced a substantial mortality shock in 2010 in this age group, and consequently recorded the largest gap from the low mortality benchmark. By 2015 the state average (33.8 years, 33.3 to 34.3) had almost recovered to its 2005 level. Trends for females are closer to the low mortality benchmark.

Among older adults, life expectancy between ages 50 and 84 shows stagnation and deterioration over the entire period of observation. Even the low mortality benchmark exhibits a gradual downward trend, pointing to a generalised mortality increase. The state average female life expectancy declined from 28.8 years (27.4 to 30.2) in 1990 to 28.3 years (27.4 to 29.2) in 2010. By 2015, this average only managed to recover to 28.6 years (27.4 to 29.8). Among males, the average over states decreased from 26.7 years (24.7 to 28.8) in 1990 to 26.3 years (24.9 to 27.6) in 2010, and 26.5 years (25.3 to 27.7) in 2015. Furthermore, we fitted three linear models by sex and for both sexes, , and the slope coefficient was significant in all of them at the level of p < .005. These results suggest that the decline observed was significant. As with young adult males, some states experienced deterioration after 2005, with a minor recovery since 2010.

[Figure 1 about here]

Health disparities between states and age groups

Figures 2-5 show results only for males because they exhibit the largest departures from the low mortality benchmark and higher inequality. Results for females are shown in the Additional file 1.

Figure 2 shows trends in inequalities between states in Mexico for males in our three age groups, as measured by the coefficient of variation (results for females are reported in Additional file 1, Figure 2). This indicator measures the between-state variation in the state-specific benchmark within each of the three age groups. Larger values are related to higher disparities between states. Trends show mixed patterns of convergence with temporary divergence around 2010, and with females in all cases showing less between-state inequality than males over the entire period studied.

There are important differences in inequality levels and trends between age groups. Since 1990, state inequality in life expectancy in the youngest age group has been decreasing. Among females, young adults show even lower between-state disparity than infants and children. However, for males in the young adult age-group there was a crossover in the early 2000's , with the coefficient of variation increasing after 2005. The highest values are observed in the period 2009-2011. By 2015, state inequalities among young adults had decreased substantially, but remained higher than that of the youngest age group. Older adults show substantially higher inequality than the other age groups over the entire period studied, but also show steady convergence between states. From 2013, both males and females show a potential rise in disparities between states, but we caution that this rise could be random variation as it only appears for 2 years (Additional file 1 Figure 2).

[Figure 2 about here]

To illustrate discordance between age groups within each state, Figure 3 shows the state ranking of temporary life expectancy for the years 2010-15 for males in each age group (see Additional file 1, Figure 3 for females' results). States at the top show the highest values in temporary life expectancy, while states in the bottom refer to the lowest expectancies. We chose to highlight those states with the most discordant age-rankings. Green and purple lines refer to selected states that show drastic changes in the ranking between different age groups. For example, Sinaloa, in the northern part of Mexico, holds the record life expectancy below age 15; however, young adults (15-49) show one of the lowest expectancies, while older adults are in the sixth position out of 32. Similar trajectories are shown with green lines for Nayarit and Michoacán in the central region, Zacatecas in the North, as well as Morelos and Guerrero from the southern region. Conversely, the pattern of age discordance in Hidalgo, Querétaro and Mexico City from the central region, and Yucatan and Puebla in the South (purple lines) is summarised by changing from a low rank in the youngest age group to a high rank in young adults, followed by low rank in older adults.

We performed a two-way ANOVA on temporary life expectancy by state and age-groups controlling for year. There was a statistically significant interaction between the effects of states and age groups [$F=12.25$, $p < .001$] indicating, as shown in Figure 3, that part of the existing variation in the country is due to variability within each state. There were also significant differences in temporary life expectancy between age groups [$p < .001$] and states [$p < .001$] reflecting between-state variability, as shown in Figure 2.

[Figure 3 about here]

Cause-decomposition analysis

In Figures 4 and 5, the Mexican states in each region are arranged according to the largest gap with the low mortality benchmark among older adult males in 2015. Figure 4 shows how causes amenable to medical service, diabetes, ischemic heart diseases (IHD), lung cancer, cirrhosis, homicide, and road traffic accidents contributed to the gap between each state and the low mortality benchmark from 1990 to 2015 for older males (ages 50-84). These are the causes of death that contributed the most to holding states back from achieving the low mortality benchmark. Light-yellow colours indicate negligible contributions, which means that are very close to the low mortality benchmark within each category. Darker red hues indicate larger contributions to the gap. If a state is improving during the period, it shows a transition from red to light-yellow.

Medically amenable causes of death show gradual improvements in most states from 1990 to 2015, bringing them closer to the benchmark in this category. However, large disparities persist between states and a strong potential for improvements remain. For example, Baja California, Sonora, Chihuahua, and Coahuila from the northern region show substantial contributions to the gap. Diabetes mortality has increasingly contributed to widening the benchmark gap in several states, including Coahuila and Tamaulipas in the North, Mexico City, Guanajuato, Mexico state, and Tlaxcala in the central region, and Puebla, Veracruz and Tabasco in the South. Similarly, IHD significantly affects the northern part of the country, while cirrhosis is mostly concentrated in the South. Lung cancer and road traffic accidents have lower contributions to the benchmark gap, but these remain important causes of death. Homicides increased the gap in this age group in some states after 2005, such as Chihuahua, Durango and Sinaloa in the North, Colima, Michoacán and Nayarit in the central region, and Guerrero in the South.

[Figure 4 about here]

Females show similar regional patterns to males, albeit of lower magnitudes. For males, causes amenable to medical service, diabetes, and IHD contributed the largest share to the gap with the low mortality benchmark among older adult females. In the youngest age group, improvements in life expectancy and in reducing the gap with the low mortality benchmark were mainly driven by causes amenable to medical service among both females and males. Finally, homicide mortality and road traffic accidents are the main drivers of the gap with the benchmark among young male adults (ages 15-49). Importantly, homicides contributed more than 2.5 years to the gap with the low mortality benchmark in 2010 in the northern state of Chihuahua, and several states from the North and South of Mexico showed substantial impacts from homicide after 2005. Results for all age-groups are shown in Additional file 1, Figures 4-9.

Potential gains and causes of death in 2015

Figure 5 breaks down the state-specific low mortality benchmark gap for males aged 50-84 into potential gains and their cause of death composition. The left panel shows the potential gains for older adults if the low mortality benchmark were achieved for each state in 2015. The right panel shows the proportion of potential gains due to specific causes of death in the same year.

Every state in Mexico could increase survival by at least one year on average in older adult ages if they were to achieve the low mortality benchmark. However, for 17 of them the gap with the benchmark is higher than 2 years, and for 3 states in the northern region it is greater than 3 years. For females, except for Sinaloa and Nayarit, all states show the potential to gain over an additional year of life between ages 50-84.

More than half of these potential gains in life expectancy between ages 50 and 84 are due to medically amenable causes, diabetes, IHD, and cirrhosis in every state in Mexico (right panel). This is true also for females. Although older males show lower impact of homicide mortality on potential gains compared to young adult males (15-49), its effect is present in almost every state, particularly in Guerrero, Morelos in the South, Nayarit and Colima in the central region, and Sinaloa in the North. Results for all the age groups for the years 2005, 2010, and 2015 are shown in the Additional file 1, Figures 10-18.

[Figure 5 about here]

Discussion

In Mexico since 1990, life expectancy in three large age groups has followed discordant patterns of rise, stagnation, and deterioration. These patterns were driven mainly by causes of death that are amenable to medical service (such as infectious and respiratory diseases) and health behaviours (such as homicides, suicide, diabetes, IHD, and cirrhosis). Patterns in these two large cause-of-death categories led to high levels of health inequality in the country.

Life expectancy below age 15 converged towards the low mortality benchmark and maximum survival in all 32 Mexican states. These results underscore public health interventions aimed at infants and children. This is supported by evidence that vaccination coverage has been achieved for the entire young population, and that health insurance coverage has improved, due to vaccination programs and the implementation of *Seguro Popular* along with improvements in previously existing health systems, respectively.[9] Causes amenable to medical service are at the heart of such improvements, consisting of decreases in infectious and respiratory diseases associated with public health interventions targeting children.[6] For example, Puebla and Tlaxcala (in the South and central regions respectively) were the states with the lowest life expectancy below age 15 in 1990, but they have since improved by more than half a year. Moreover, the average over states improved from 14.5 in 1990 to 14.8 in 2015, with no state below 14.7. Because of continuous and nationwide convergence towards the low mortality benchmark, inequalities between states in life expectancy below age 15 have been reduced.

Opposing the optimistic trend of infants and children, increases in homicide mortality reversed gains in male life expectancy, particularly between ages 15-49. These results are consistent with previous studies quantifying the effect of homicide mortality on the stagnation of national life expectancy at birth in the first decade of the 21st century,[3] and with the reversal experienced in life expectancy in most states between 2005 and 2010.[14] Our results extend such findings by adding five years of data and segmenting by three age groups capturing stages of the life course.[34] We found that after ten years of the unexpected rise in homicide mortality, most states have experienced a slow and partial recovery since 2010. However, the impact of homicide is still higher than the levels observed pre-2005. Between 2010 and 2015, homicides accounted for most of the gap between states and the low mortality benchmark in ages 15-49. For this age group, the states that show the greatest benchmark gap for homicide in 2015 are Guerrero in the South, and Sinaloa and Chihuahua in the North, which could gain one year, and half a year (each) respectively if homicides were reduced to the level of the southern state of Yucatán, which in this case makes up 100% of the benchmark. Moreover, health inequalities in life expectancy between states followed the rise in homicides after 2005 (Figure 2), and the considerable discordance between age-groups (Figure 3) was likely due in great part to homicide mortality in ages 15-49. It is unclear how these levels of state life expectancy will change with the new reports which highlight a three year increase in homicide in Mexico.[23,ii] Further, the exposure that people have had to violence has triggered mental health problems, e.g. a widespread heightened perception of vulnerability.[15] At the same time suicide is strongly linked to mental disorders.[35] Thus, if the Mexican health system does not have proper interventions to handle the mental health needs of the population, an increase in suicides might be observed in the future.

The population aged 50-84 shows the largest low mortality benchmark gap in both females and males. Out of 35 liveable years in this age group, females lived on average 28.6 years and males 26.5 in 2015 without any clear improvement in the 26 years since 1990. Even the low mortality benchmark itself shows a downward trend for males and females (Figure 1). Moreover, this age group exhibits the highest inequality between states in the last 26 years. Our results show that causes of death holding states back from the low mortality benchmark vary between regions. Causes amenable to medical service showed gradual improvements in almost every state since

1990. However, in some states of the northern region such as Baja California, Sonora, and Chihuahua, these causes of death still show large room for improvements among older adults. Diabetes, Ischemic Heart Diseases (IHD) and cirrhosis account for most of the gap with the benchmark mortality, these display large regional differences. For example, IHD is mostly concentrated in the North (Figure 4), while cirrhosis and diabetes show a stronger impact in the central and southern regions. These results are supported by previous evidence documenting an increase in adult mortality rates from chronic kidney disease, diabetes, and cirrhosis since 2000.[16] Lung cancer and homicides had a lower impact on life expectancy for this age group, and both are higher in the northern part of the country.

Strengths and limitations of the study

Our analytical approach enables us to measure the years of life expectancy that could be gained in Mexican states by improving medically amenable mortality and behaviour-related mortality to the lowest levels presently observed in Mexico. This concept allows us to analyse patterns in life expectancy for different age groups over time and simultaneously account for changes in causes of death and inequality between states that have undergone major social and public health transitions.

The limitations of our study should be mentioned. First, Mortality data from Mexico are likely to present inaccuracies in cause-of-death classification due to comorbidities, particularly at older ages.[36] To mitigate this, we focus on ages below 85 and broad cause-of-death groups. In addition, road traffic accidents and homicides may happen not in the place of residence but in another state, which might cause differences in state specific mortality. Moreover, our estimates regarding homicide mortality are likely to be underestimated due to inaccurate coding and reporting practices, and due to the large number of missing individuals in Mexico.[37 38] Similarly, in 1997 a change in diagnosis criterion for diabetes took place, and this could have an impact on trends of mortality caused by diabetes in years adjacent to 1997.[39] In addition, underreported deaths and ill-defined causes of death could potentially bias our results. Mexico is considered to have high-quality data according to the Pan American Health Organization's criteria. Underreported deaths are estimated to be around 0.8%,[40 41] while ill-defined causes of death fell from 2.1% of all deaths around 2000 to 1.7% more recently.[40] We expect our main findings to be robust given the small percentages of ill-defined and underreported deaths. Finally, small population sizes could bias our results. As a robustness check, we calculated Confidence Intervals (95%) for all our estimates of temporary life expectancy, including the benchmark (see Supplementary material), and did not find major differences with our main results.

Avoidable mortality should be understood as an indicator of potential weaknesses with respect to health care and some public health policies and not as a definitive assessment.[10] The number of deaths that should be considered avoidable is not clear [42]. For instance, some researchers consider only half of heart disease mortality to be avoidable.[43 44] There is no direct information to precisely measure percentages of avoidable mortality within cause groups in Mexico. Nonetheless, the difference between a given mortality schedule and the best mortality schedule of the same year can be conceived of as a minimal definition of avoidable mortality. The benchmark mortality schedule sets a lower bound to how much mortality could have been avoided.

Certainly, even the best mortality schedule will contain elements of mortality that most would consider avoidable. To the extent that the components of the benchmark schedule were indeed attained somewhere in Mexico, one can view any excess mortality with respect to the benchmark schedule as presently avoidable. We believe this perspective improves on the AM concept by giving a directly measurable standard against which to estimate avoidable deaths.

Implications of findings

Beyond the mortality implications of the rise in homicide, violence has had a toll on perceived vulnerability in the country.[15] The recent increase in homicides in some states could trigger an increase in the perception of vulnerability, which would result in a higher average lifetime experience of fear in specific states. Although we are not able to link the trends in mortality among young adults in Mexico with specific public policies, some evidence suggests that the propagation of homicide mortality is not only a result of the war between drug cartels, but also because of the implementation of specific policies aimed to mitigate drug cartel operations after 2006.[45] There is no simple way to lessen the impact of homicide mortality, but it is clear that the government has not been able to reduce its burden to levels observed before 2005. Furthermore, state homicide rates may underestimate the effect of violence in particular localities. For example, Guerrero in the South, has two of the most dangerous cities in the world,[iii] but no information is available on the heterogeneity in homicide mortality for the rest of the state.

The fact that in 2015 older adults in Mexico could add more than one year of life in every state for males, and in 30 states for females by achieving the benchmark mortality levels, underscores vulnerability in these ages. Public health interventions targeting specific causes of death for this age group according to the epidemiological profile of each state would not only increase state life expectancy, but it would also forge a path towards more equality between states in health outcomes. More than half of the potential gains in life expectancy between ages 50 and 84 are due to avoidable mortality, and to a large extent mortality related to health behaviours and medically amenable causes. For instance, obesity and overweight, risk factors for diabetes and IHD, have dramatically increased since the 1990s in developing countries because of the consumption of cheap, energy-dense food and reduced physical activity.[46] Mexico, along with the USA, has the highest prevalence of overweight and obesity among all OECD countries[20] and one of the highest in Latin America, along with Chile, El Salvador, Honduras, and Paraguay.[47] However, obesity prevalence is not homogeneous across Mexico. The highest rates of obesity are concentrated in the northern and central regions[20] and in urban areas of the country,[48] which roughly matches our regional pattern of IHD and diabetes mortality.

Conclusion

Mexico stands today at an advanced stage of the epidemiological transition.[16] However this transition was achieved rapidly and the health system is ill-prepared for the burden of non-communicable diseases.[49] The cardiovascular mortality reductions that brought the developed world into advanced levels of life expectancy, are still in progress in Mexico. Nevertheless, no single solution is available to reduce behavioural mortality in this country since, as we show, great heterogeneity in mortality levels exist between states.

Signs of a fragile situation in the health and mortality of the oldest age group is highlighted by the decline in the low mortality benchmark used in our analysis. Population ageing could scale up this situation if timely preventive measures are not put in place. Furthermore, a resurgence of violent deaths [14 15 21] has created a new burden in Mexican society.

As is the case in many developing countries, Mexico will have to face these new challenges with a broad strategy. This should include a continuous and adaptable health system ready for the current and future health adversities at the physical, mental, and societal levels. Many other institutions will also have to coevolve including importantly the development of an education system that embraces and encourages physical and healthy activities to diminish risk factors that contribute to the high prevalence of obesity and cirrhosis in Mexico. Finally, the burden of violence in recent years demonstrates the failure of current policies trying to mitigate violence in the country. New strategies that replace current ones are needed and embracing evidence based policies (e.g. drug policies) could be a new venue to eradicate the consequences of violence on the Mexican population.

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Competing interest statement: All authors have completed the Unified Competing Interest form and declare: no support from any organisation for the submitted work; no financial relationships with any organisations that might have an interest in the submitted work in the previous three years, no other relationships or activities that could appear to have influenced the submitted work.

Data sharing: All data used are publicly available in references 22 and 23. All the study is fully replicable at https://github.com/jmaburto/DecompMex

Transparency: The lead author* affirms that this manuscript is an honest, accurate, and transparent account of the study being reported; that no important aspects of the study have been omitted; and that any discrepancies from the study as planned (and, if relevant, registered) have been explained.

Ethical approval: No ethical approval was needed from the institutions' boards since we work with anonymised aggregated publicly available datasets.

Figures

Figure 1. State-specific life expectancy trends (grey), average (black) and low mortality benchmark (blue) for three age groups, the youngest (0-14), young adults (14-49), and older adults (50-84) by sex for the period 1990-2015. Source: calculations based on INEGI and CONAPO files.

Figure 2. Inequality in male life expectancy between states for the youngest (0-14), young adults (15-49) and older adults (50-84), 1990-2015. Source: calculations based on INEGI and CONAPO files.

Figure 3. Discordant age-rankings for average male life expectancy 2010-15 for the youngest (0-14), young adults (14-49), and older adults (50-84). Source: calculations based on INEGI and CONAPO files.

Figure 4. Cause-specific contributions to the gap between states and low mortality benchmark for older male adults (50-84), 1990-2015. Source: calculations based on INEGI and CONAPO files.

Figure 5. State-specific gap with the low mortality benchmark and its cause-of-death composition for older male adults (50-84) in 2015. Source: calculations based on INEGI and CONAPO files.

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Endnotes

[i] The percentage of the population aged 65 or older is projected to go from 6.0% in 2015 to 10.2% in 2030 (Reference: CONAPO)

[ii] [https://www.businessinsider.com.au/homicides-hit-new-high-mexico-alongside-increase-in-robberies-2017-11?r=US&IR=T]

[iii] [http://www.economist.com/blogs/graphicdetail/2017/03/daily-chart-23]

Additional Files

Additional file 1 | Supplemental material

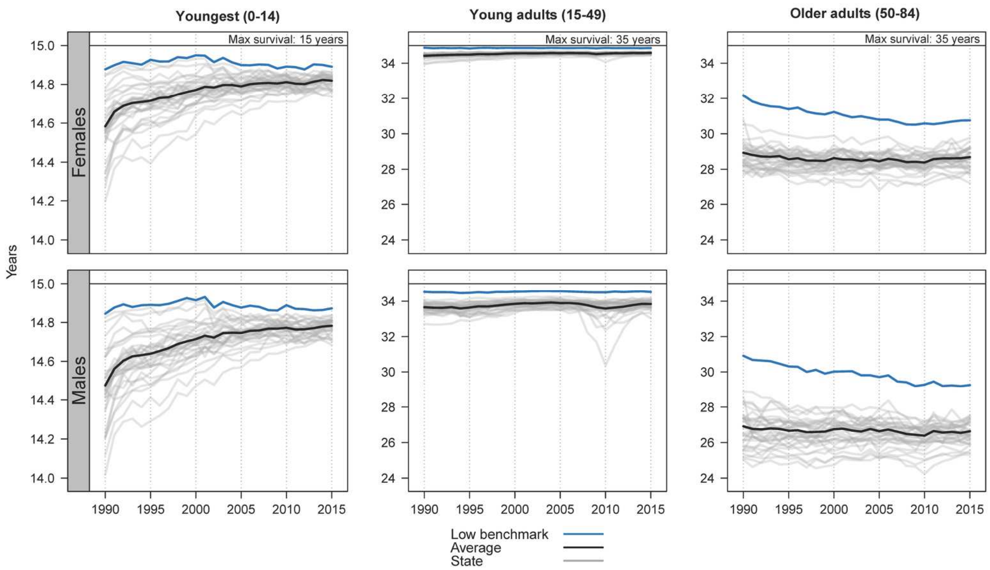

Figure 1. State-specific life expectancy trends (grey), average (black) and low mortality benchmark (blue) for three age groups, the youngest (0-14), young adults (14-49), and older adults (50-84) by sex for the period 1990-2015. Source: calculations based on INEGI and CONAPO files.

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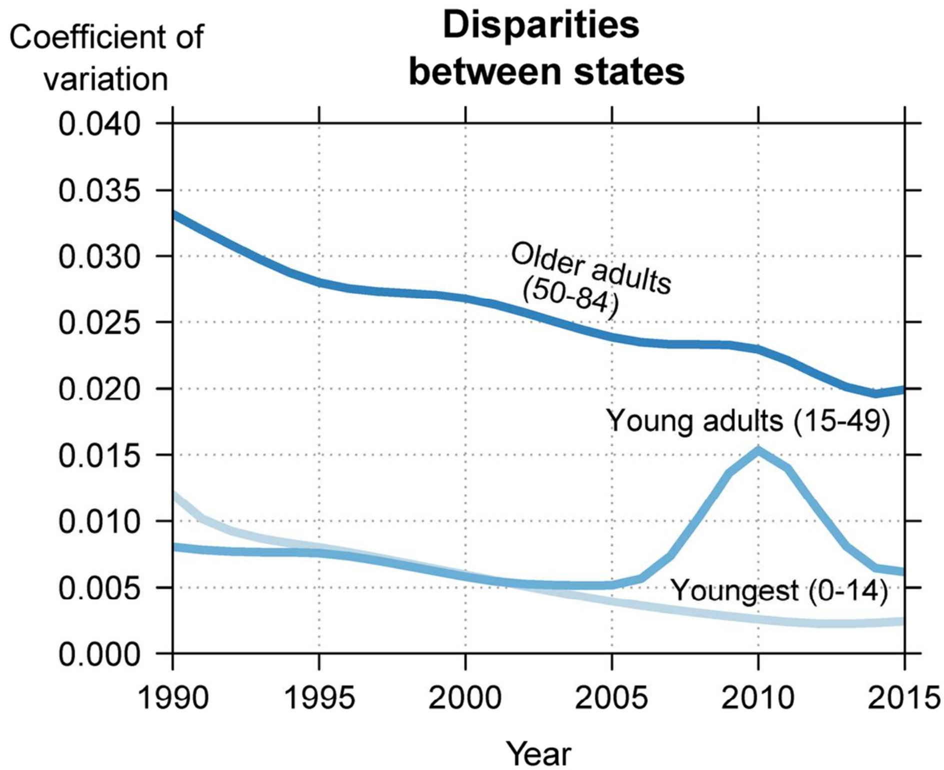

Figure 2. Inequality in male life expectancy between states for the youngest (0-14), young adults (15-49) and older adults (50-84), 1990-2015. Source: calculations based on INEGI and CONAPO files.

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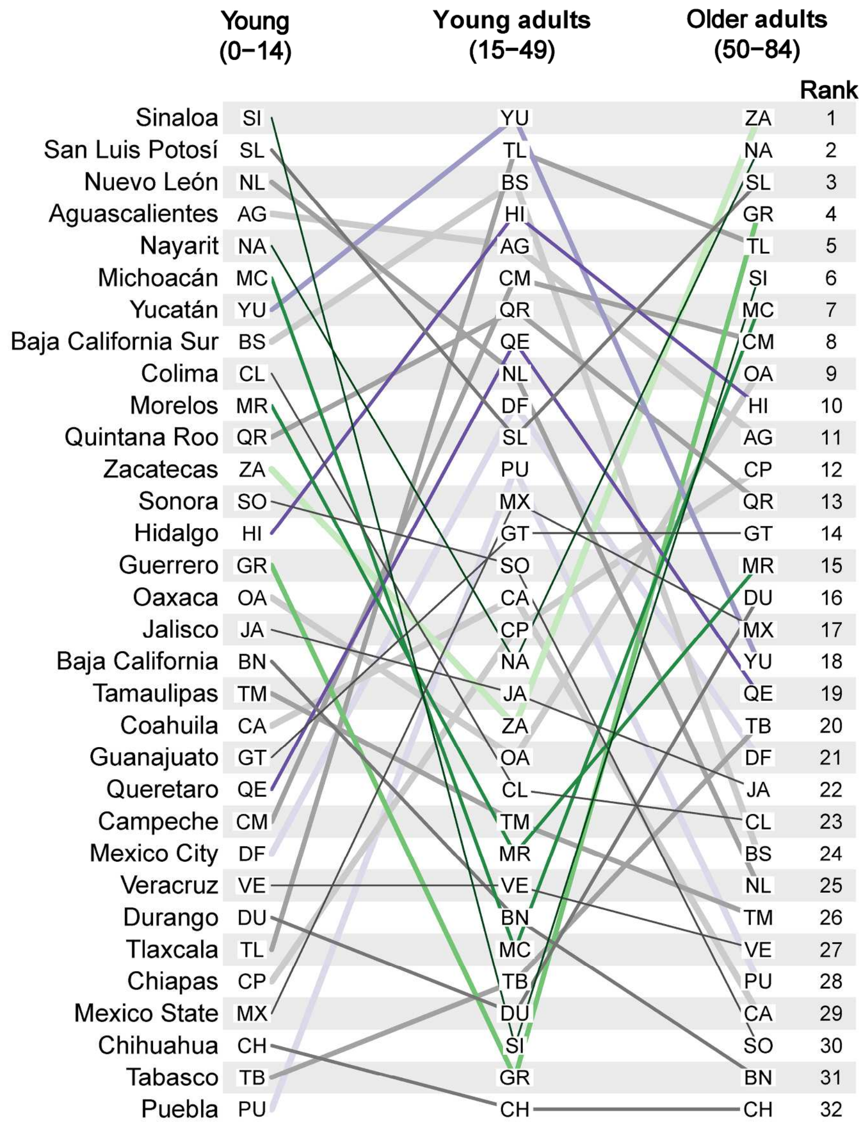

Figure 3. Discordant age-rankings for average male life expectancy 2010-15 for the youngest (0-14), young adults (14-49), and older adults (50-84). Source: calculations based on INEGI and CONAPO files.

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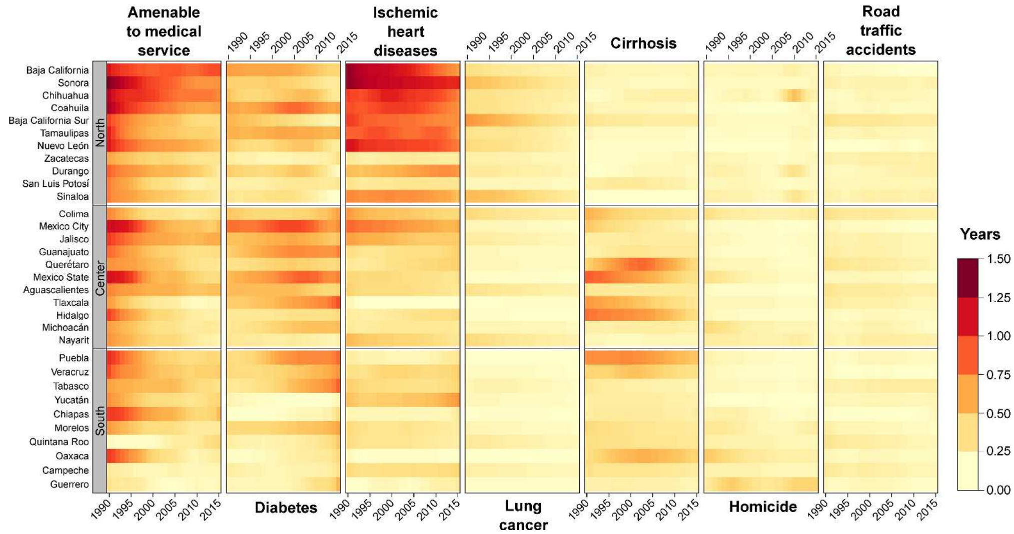

Figure 4. Cause-specific contributions to the gap between states and low mortality benchmark for older male adults (50-84), 1990-2015. Source: calculations based on INEGI and CONAPO files.

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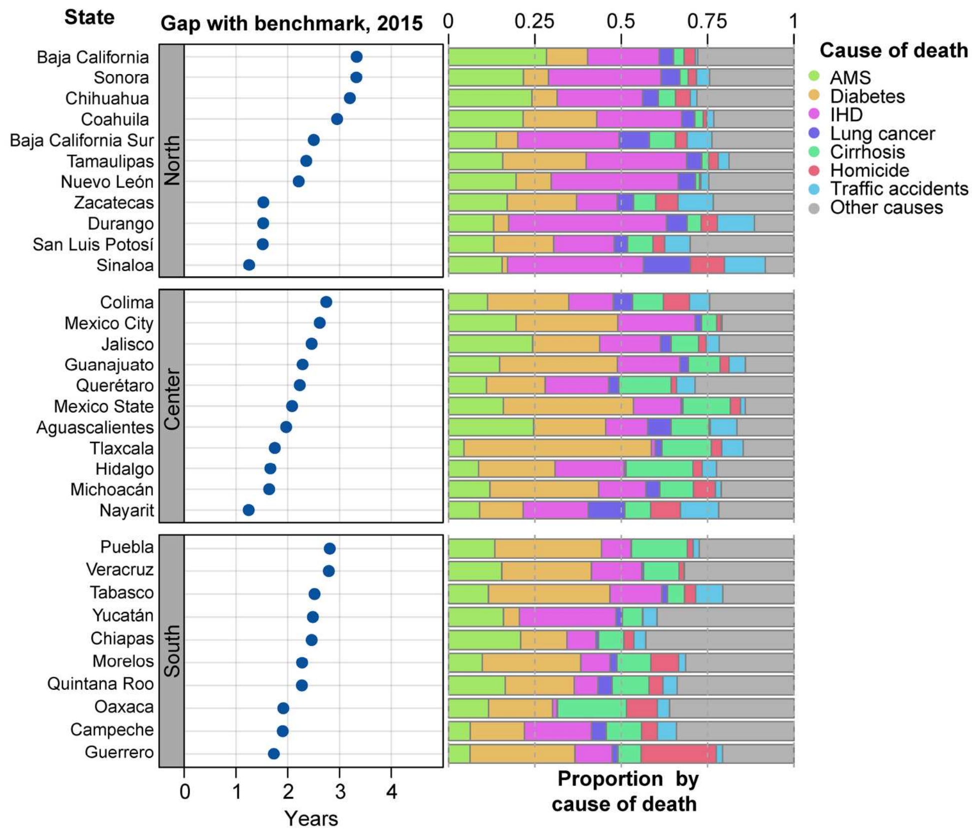

Figure 5. State-specific gap with the low mortality benchmark and its cause-of-death composition for older male adults (50-84) in 2015. Source: calculations based on INEGI and CONAPO files.

177x155mm (300 x 300 DPI)

Trends in avoidable mortality over the life course in Mexico, 1990-2015: A cross-sectional demographic analysis

José Manuel Aburto[1], Tim Riffe[2], and Vladimir Canudas-Romo[3]

[1]University of Southern Denmark
[2]Max Planck Institute for Demographic Research
[3]School of Demography, Australian National University

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Abstract

Objective:To analyse average lifespan and quantify the effect of Avoidable/Amenable mortality on the dif-ference between state-specific mortality and a low-mortality benchmark in Mexico during 1990-2015.

Design: Retrospective cross-sectional demographic analysis using aggregated data.

Setting: Vital statistics from the Mexican civil registration system.

Participants: Aggregated national data (from 91.2 million people in 1995 to 119.9 in 2015) grouped in 64 populations (32 Mexican-states [including Mexico City] by sex) with cause-of-death data.

Main outcome measures: Cause-specific contributions to the gap in life expectancy with a low-mortality benchmark in three age groups (0-14, 15-49 and 50-84).

Results: Infants and children under age 15 show improvements towards maximal survival in all states. However, adult males aged 15 to 49 show deterioration after 2006 in almost every state due to increasing homicides, and a slow recovery thereafter. Out of 35 potential years, females and males live on average 34.57 (34.48 to 34.67) and 33.80 (33.34 to 34.27), respectively. Adults aged 50 to 84 show an unexpected decrease in the low mortality benchmark, indicating nationwide deteriora-tion among older adults. Females and males in this age group show an average survival of 28.59 (27.43 to 29.75) and 26.52 (25.33 to 27.73) out of 35 potential years, respectively. State gaps from the benchmark were mainly caused by ischemic heart diseases, diabetes, cirrhosis and homi-cides. We find large health disparities between states, particularly for the adult population after 2005.

Conclusions: Mexico has succeeded in reducing mortality and between-state inequalities in children. However, adults are becoming vulnerable as they have not been able to reduce the burden of violence and conditions amenable to health services and behaviours, such as diabetes, ischemic heart diseases and cirrhosis. These trends have led to large health disparities between Mexican states in the last 25 years.

Supplemental material

Appendix Table 1. Definitions of cause-of-death categories using the 9th and 10th revision of the International Classification of Diseases.

Category	ICD-10	ICD-9
I. Amenable to medical service		
I.A. AM-Infectious & respiratory diseases : intestinal infections, tuberculosis, zoonotic bacterial diseases, other bacterial diseases, septicemia, poliomyelitis, measles, rubella, infectious hepatitis, ornithosis, rickettsioses/ arthropod-borne, syphilis (all forms), yaws, respiratory diseases, influenza & pneumonia, chronic lower respiratory diseases	A00-A09, A16-A19, B90, A20-A26, A28, A32, A33, A35, A36, A37, A40-A41, A80, B05-B06, B15-B19, A70, A68, A75, A77, A50-A64, A66, J00-J08, J20-J39, J60-J99, J09-J18, J40-J47	001-009, 010-018, 32, 33, 37, 137, 020-027, 38, 45, 55-56, 70, 73, 080-082, 087, 090-099, 102, 460-479, 500-519, 480-488, 490-496
I.B. AM-Cancers: malignant neoplasm of colon, skin, breast, cervix, prostate, testis, bladder, kidney-Wilm's tumor only, eye, thyroid carcinoma, Hodgkins disease, leukemia	C16,C18-C21, C43-C44, C50, C53, C61, C62, C67, C64, C69, C73, C81, C91-C95	153-154, 172-173, 174, 180, 185, 186, 188-189, 190, 193, 201, 204-208
I.C. AM-Circulatory: active/acute rheumatic fever, chronic rheumatic heart disease, hypertensive disease, cerebrovascular disease	I00-I02, I05-I09, I10-I13, I15, I60-I69	390-392, 393-398, 401-405, 430-438
I.D. AM-Birth: maternal deaths (all), congenital cardiovascular anomalies, perinatal deaths (excluding stillbirths)	O00-O99, Q20-Q28, P00-P96	630-676, 745-747, 760-779
I.E. AM-Other: disease of thyroid, epilepsy, peptic ulcer, appendicitis, abdominal hernia, cholelithiasis & cholecystitis, nephritis, benign prostatic hyperplasia, misadventures to patients during surgical or medical care, cisticerchosis	E00-E07, 40-G41, K25-K27, K35-K38, K40-K46, K80-K81, N00-N07, N17-N19, N25-N27, N40, Y60-Y69, Y83-Y84, B69	240-246, 345, 531-533, 540-543, 550-553, 574-575.1, 580-589, 600, E870-E876, E878-E879
II. Diabetes	E10-E14	250
III. Ischemic Heart Diseases (IHD)	I20-I25	410-414, 429.2
IV. Lung cancer	C33-C34	162
V. Cirrhosis	K70	571.1-571.3
VI. Homicides	X85-Y09	E960-E969
VII. Road traffic accidents	V01-V99	E810-E819
VIII. Suicide and self-inflicted injuries	E950-E959	X60-X84, Y87.0
IX. Residual Causes : HIV/AIDS; other cancers and other heart diseases	B20-B24, U03; C00-D48; I00-I99 if not listed above; R00-R99	042-044;140-239; 390-459 if not listed above; 780-799

Temporary Life Expectancy

Temporary life expectancy between ages x_1 and x_2, for $x_1 < x_2$, is defined as the average years of life lived between these ages according to a given set of mortality rates (Arriaga 1984). We denote this quantity as ${}_{(x_2-x_1)}e_{x_1}$, and its benchmark based on minimum death rates for every age and cause of death among the Mexican states for each year as ${}_{(x_2-x_1)}e^{\star}_{x_1}$. Defined in terms of the lifetable survival function, $\ell(x)$:

$$ {}_{(x_2-x_1)}e_{x_1} = \frac{\int_{x_1}^{x_2} \ell(x)\,\mathrm{d}x}{\ell(x_1)} \tag{1} $$

If full survival is achieved, the life expectancy is $x_2 - x_1$. For example, if we set $x_1 = 0$ and $x_2 = 15$, and no person dies between the ages 0 and 15, on average the population lives 15 full years.

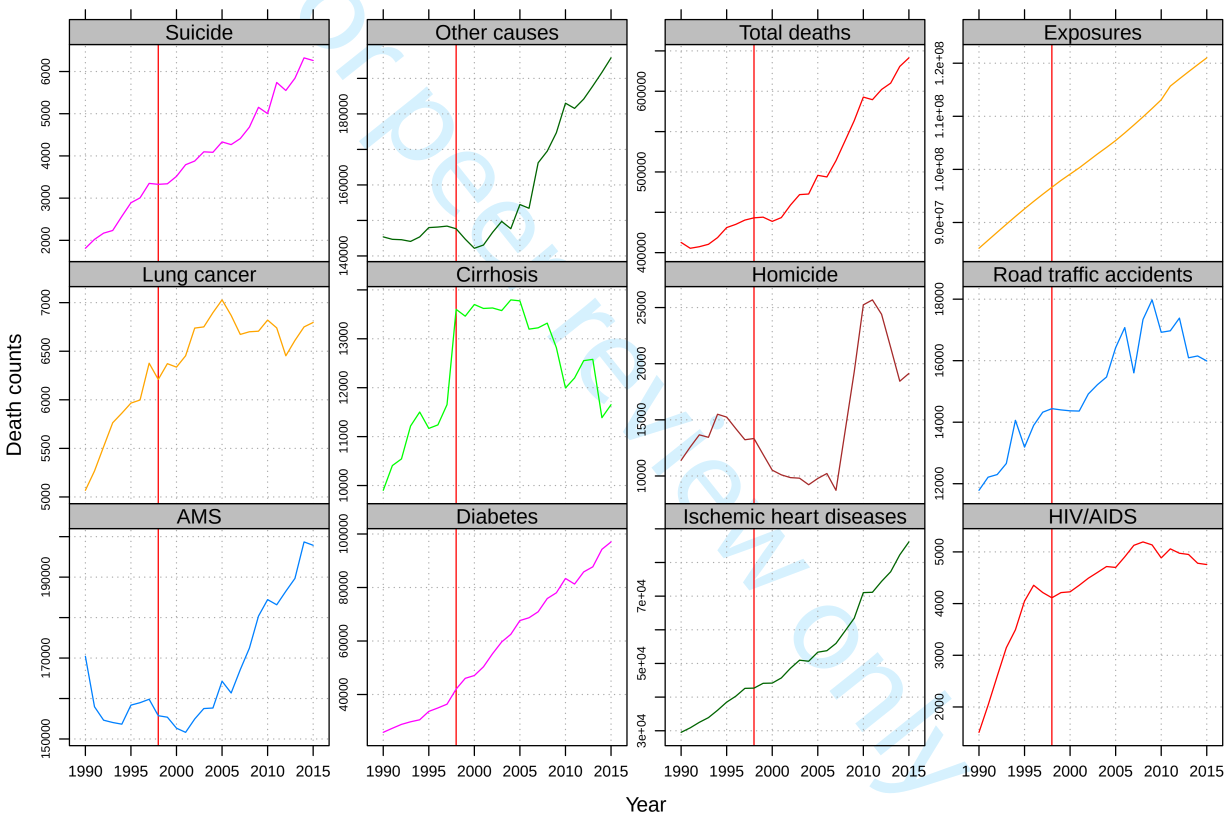
Decomposition method

The decomposition method used in this paper relies on a model of demographic functions based on continuous change (Horiuchi et al. 2008). Suppose P (e.g. temporary life expectancy between ages 15 and 49) is a differentiable function of n covariates (e.g. each age-cause specific mortality rate) denoted by the vector $\boldsymbol{A} = [x_1, x_2, \ldots, x_n]^T$. We assume that $\boldsymbol{A}$ is a differentiable function between P_1 and P_2, then the difference in P between P_1 and P_2 can be expressed as follows:

$$ P_2 - P_1 = \sum_{i=1}^{n} \int_{x_i(P_1)}^{x_i(P_2)} \frac{\partial P}{\partial x_i} dx_i = \sum_{i=1}^{n} c_i, \tag{2} $$

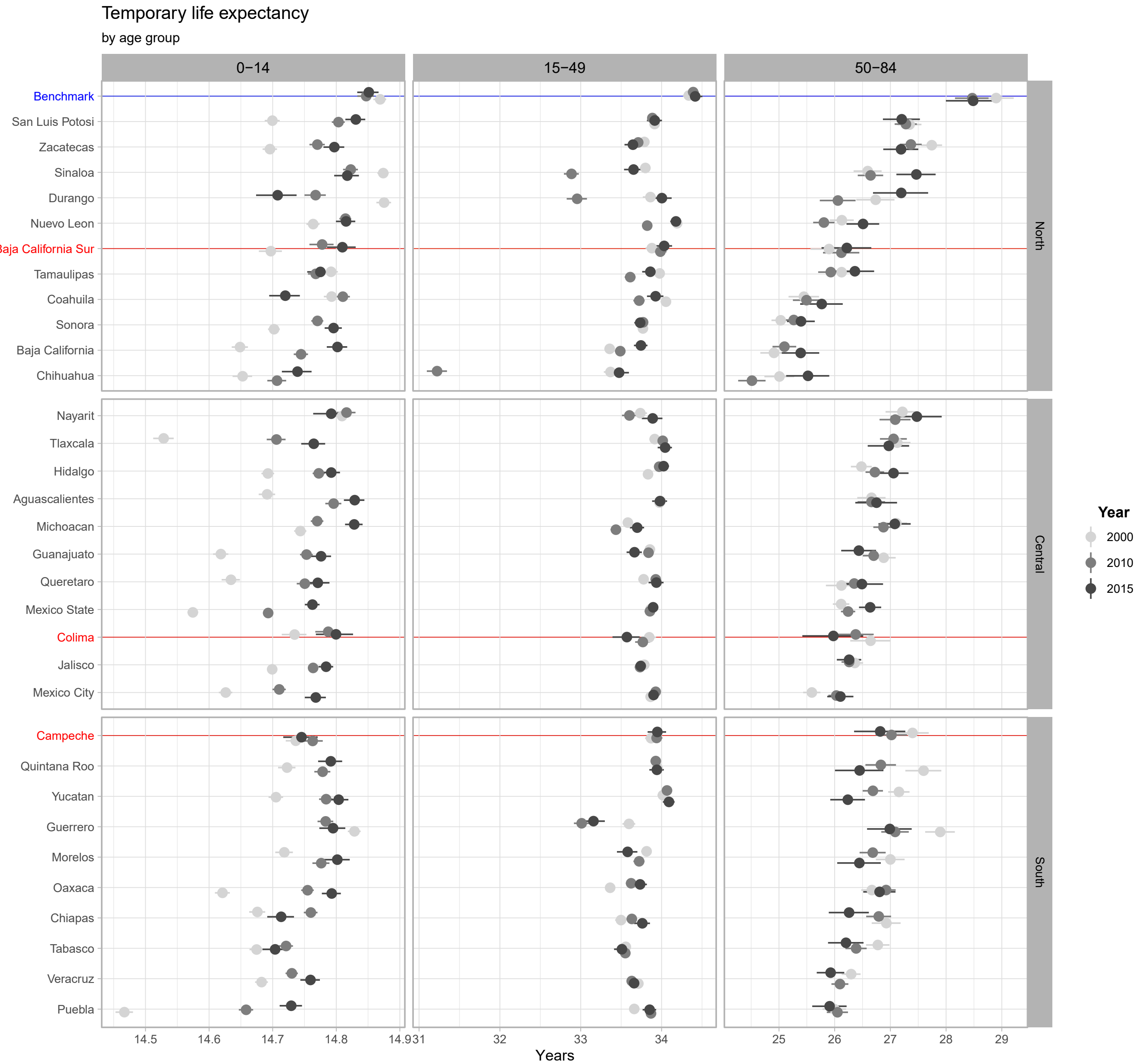
where c_i is the total change in P produced by changes in the i-th covariate, x_i. The c_i's in equation (2) were computed by numerical integration following the algorithm suggested by Horiuchi et al. (2008). This method has the advantage of assuming that covariates change gradually along the time dimension.

Figure 1: Cause-specific death counts (different y-scale for each cause), 1990-2010.



Note: AMS "amenable to medical service". The red line indicates the change from ICD 9 to ICD 10.

Robustness check: 95% CIs for male temporary life expectancies



Note: States highlighted in red had less than 1 million population in 2010.

References

Arriaga, E. E. (1984). Measuring and explaining the change in life expectancies. *Demography*, 21(1):83–96.

Horiuchi, S., Wilmoth, J. R., and Pletcher, S. D. (2008). A decomposition method based on a model of continuous change. *Demography*, 45(4):785–801.

Figure 2: Inequality in life expectancy between states for youngest (0-14), young adults (15-49), and older adults (50-84) by sex, 1990-2015.

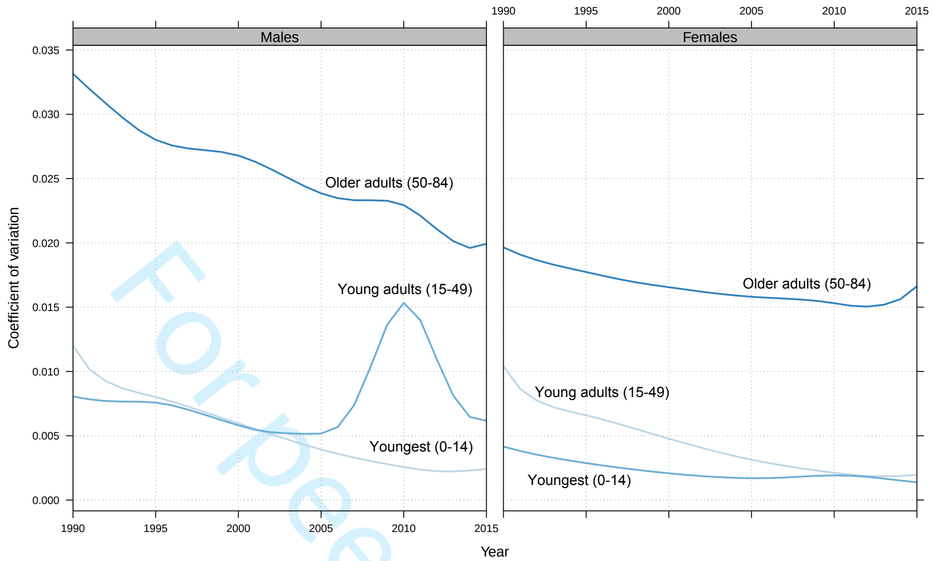
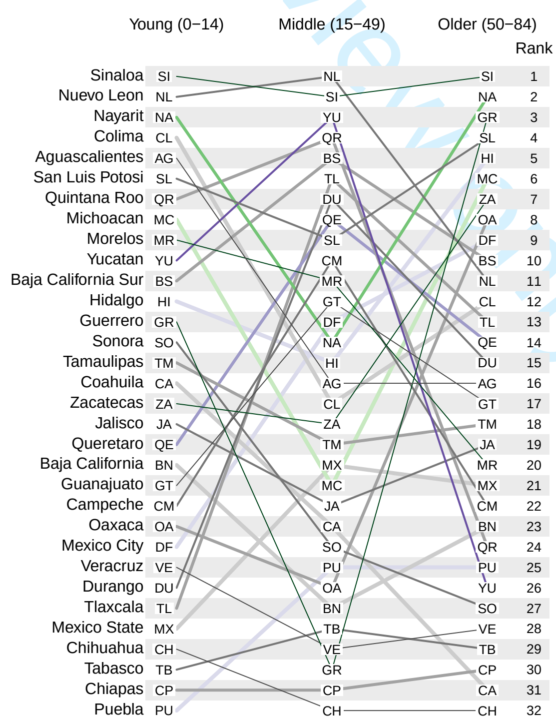
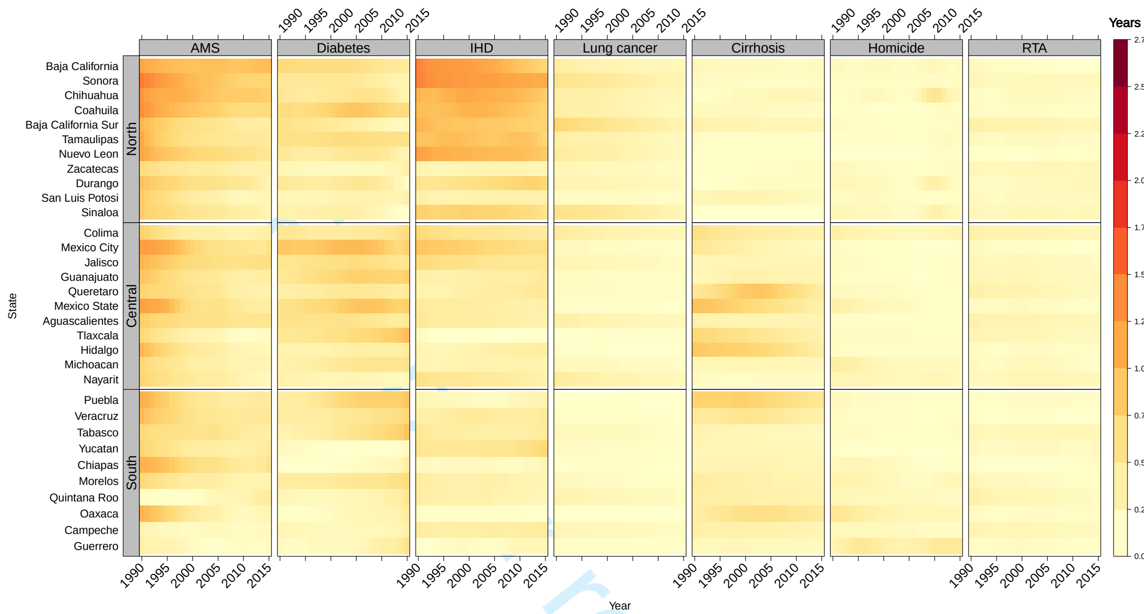


Figure 3: State ranking for average female life expectancy 2010-15 for the youngest (0-14), young adults (15-49), and older adults (50-84).



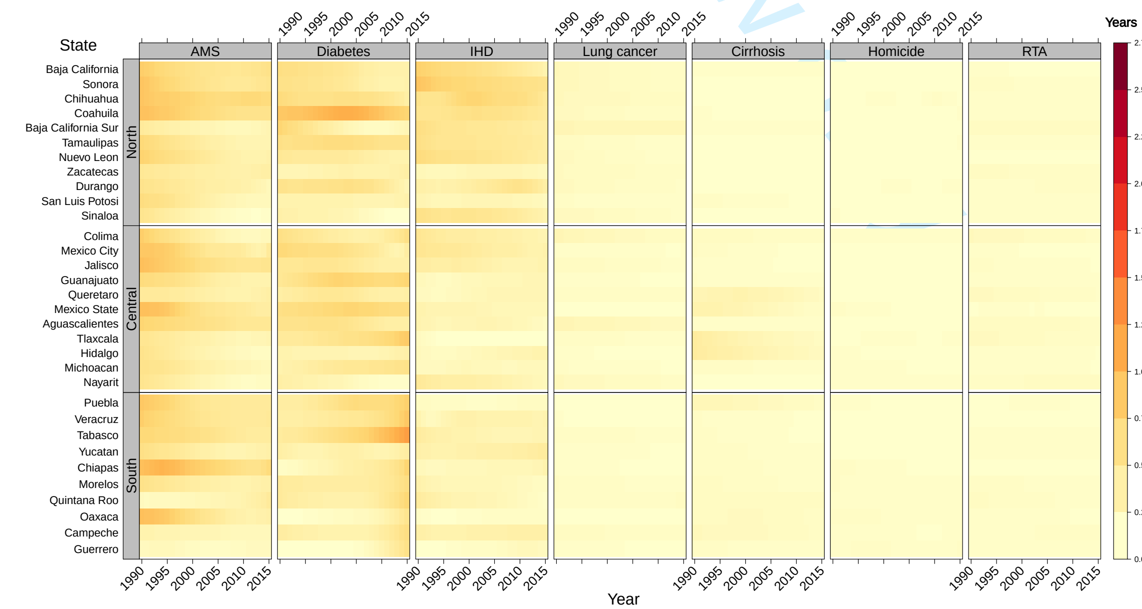
Source: calculations based on INEGI and CONAPO files.

Figure 4: Cause-specific contributions to state differences from low mortality benchmark for older male adults (ages 50-84), 1990-2015. States grouped into three regions. Reproduced from manuscript Figure 4 to have color scale comparable with other Supplementary figures. In subsequent figures 5-9 the color was rescaled to make them comparable over age groups in the supplemental material, the maximum value observed was 2.6 years caused by homicides in Chihuahua in 2010.



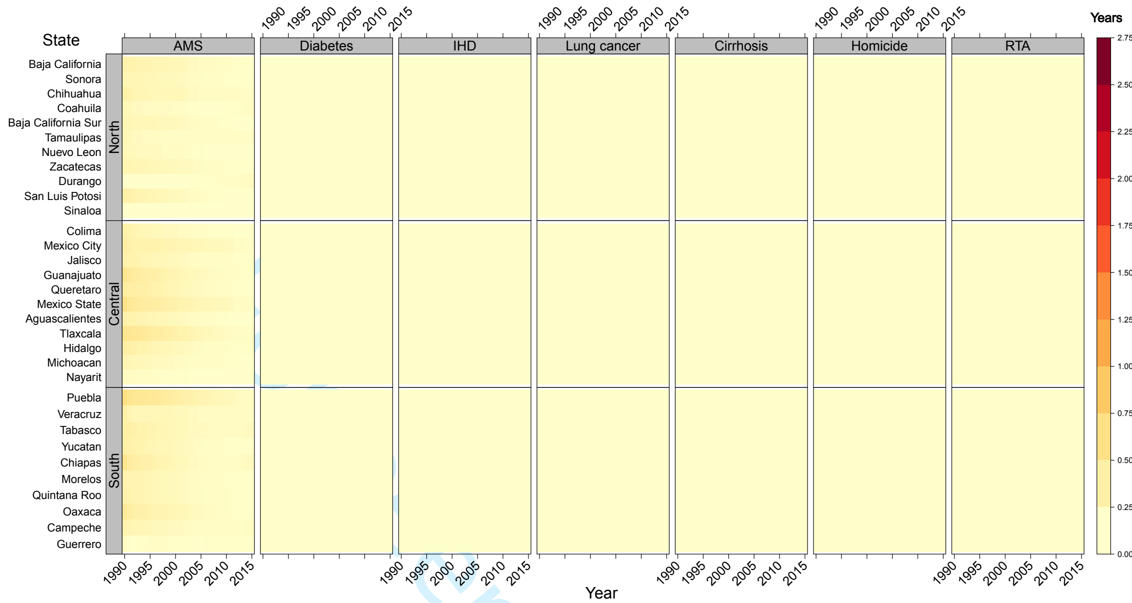
Note: AMS is "amenable to medical service", IHD is "isquemic heart diseases", and RTA is "road traffic accidents". Source: own calculations.

Figure 5: Cause-specific contributions to state differences from low mortality benchmark for older female adults (ages 50-84), 1990-2015.



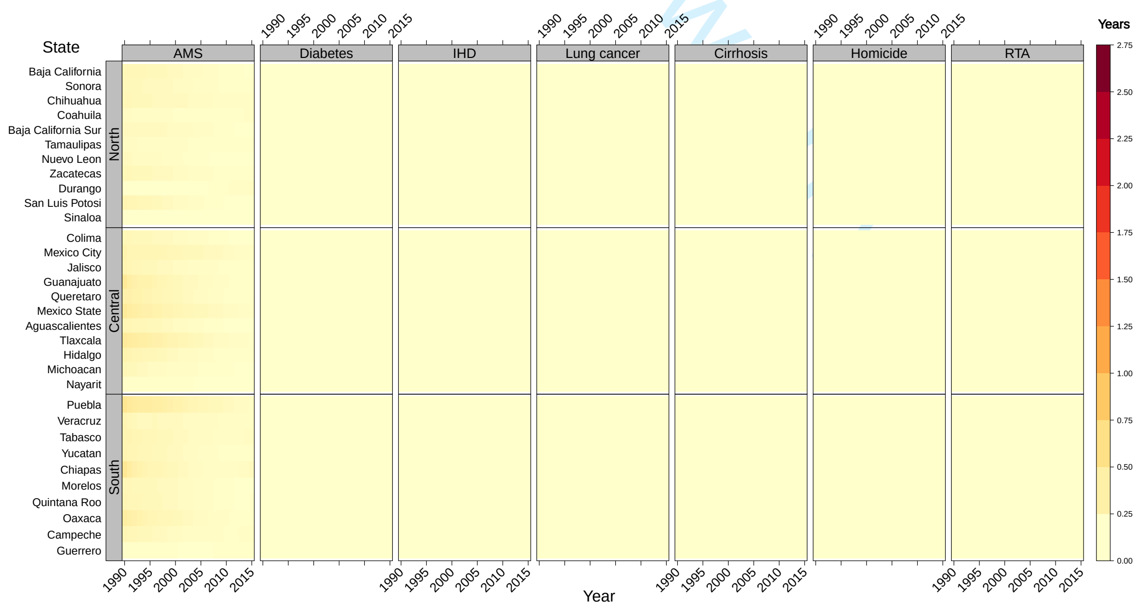
Note: AMS is "amenable to medical service", IHD is "isquemic heart diseases", and RTA is "road traffic accidents". Source: own calculations.

Figure 6: Cause-specific contributions to state differences from low mortality benchmark for male youngest population (ages 0-14), 1990-2015.



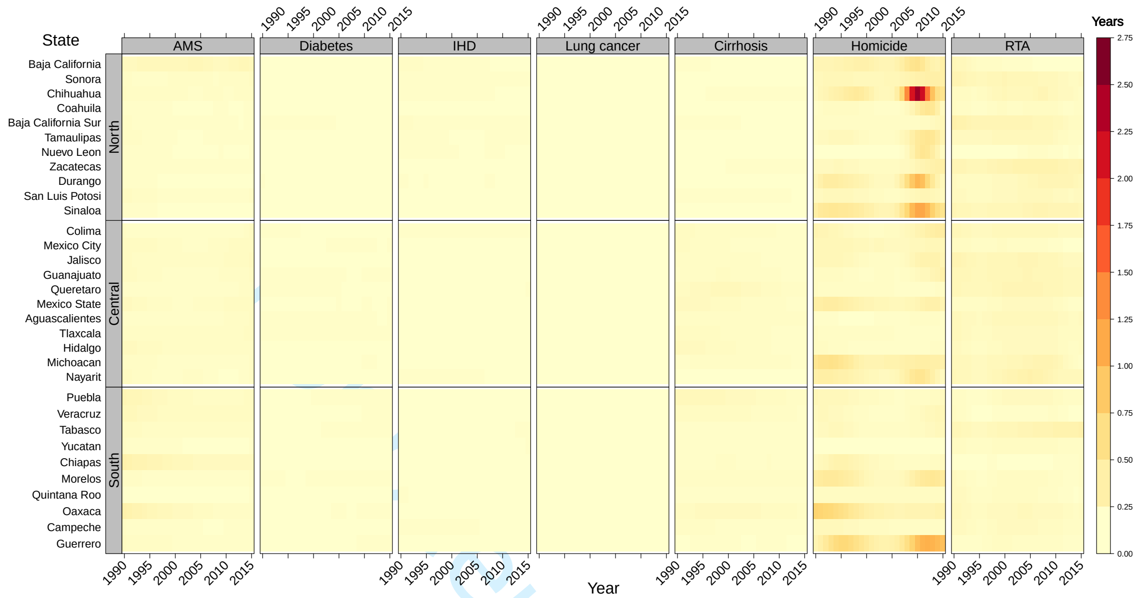
Note: AMS is "amenable to medical service", IHD is "isquemic heart diseases", and RTA is "road traffic accidents". Source: own calculations.

Figure 7: Cause-specific contributions to state differences from low mortality benchmark for female youngest population (ages 0-14), 1990-2015.



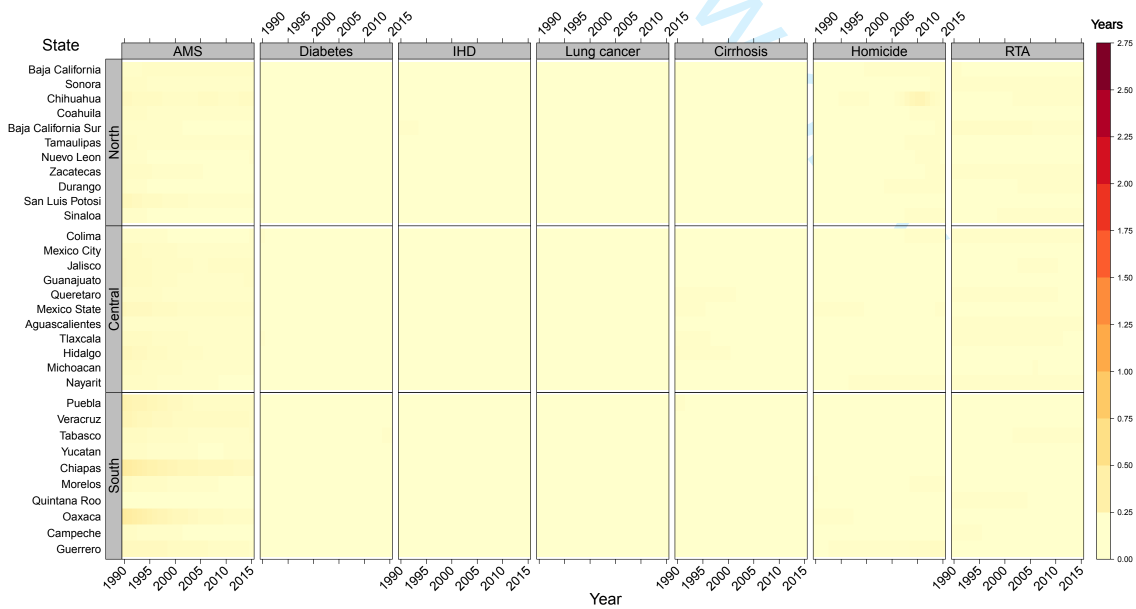
Note: AMS is "amenable to medical service", IHD is "isquemic heart diseases", and RTA is "road traffic accidents". Source: own calculations.

Figure 8: Cause-specific contributions to state differences from low mortality benchmark for male young adults (ages 15-49), 1990-2015.



Note: AMS is "amenable to medical service", IHD is "isquemic heart diseases", and RTA is "road traffic accidents". Source: own calculations.

Figure 9: Cause-specific contributions to state differences from low mortality benchmark for female young adults (ages 15-49), 1990-2015.



Note: AMS is "amenable to medical service", IHD is "isquemic heart diseases", and RTA is "road traffic accidents". Source: own calculations.

Figure 10: State specific gap with low mortality benchmark for selected years between ages 0-14. Source: own calculations.

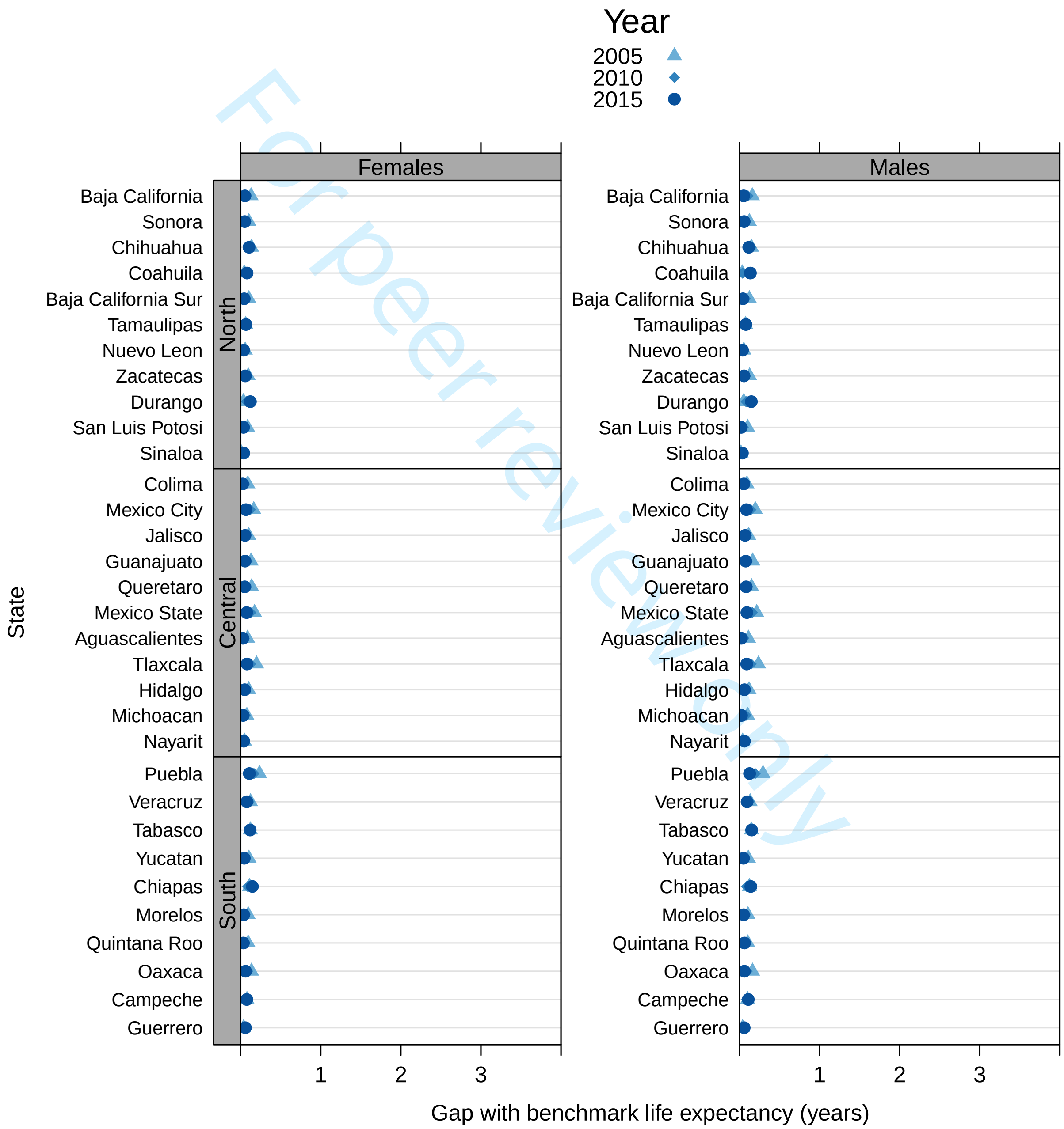


Figure 11: State specific gap with low mortality benchmark for selected years between ages 15-49. Source: own calculations.

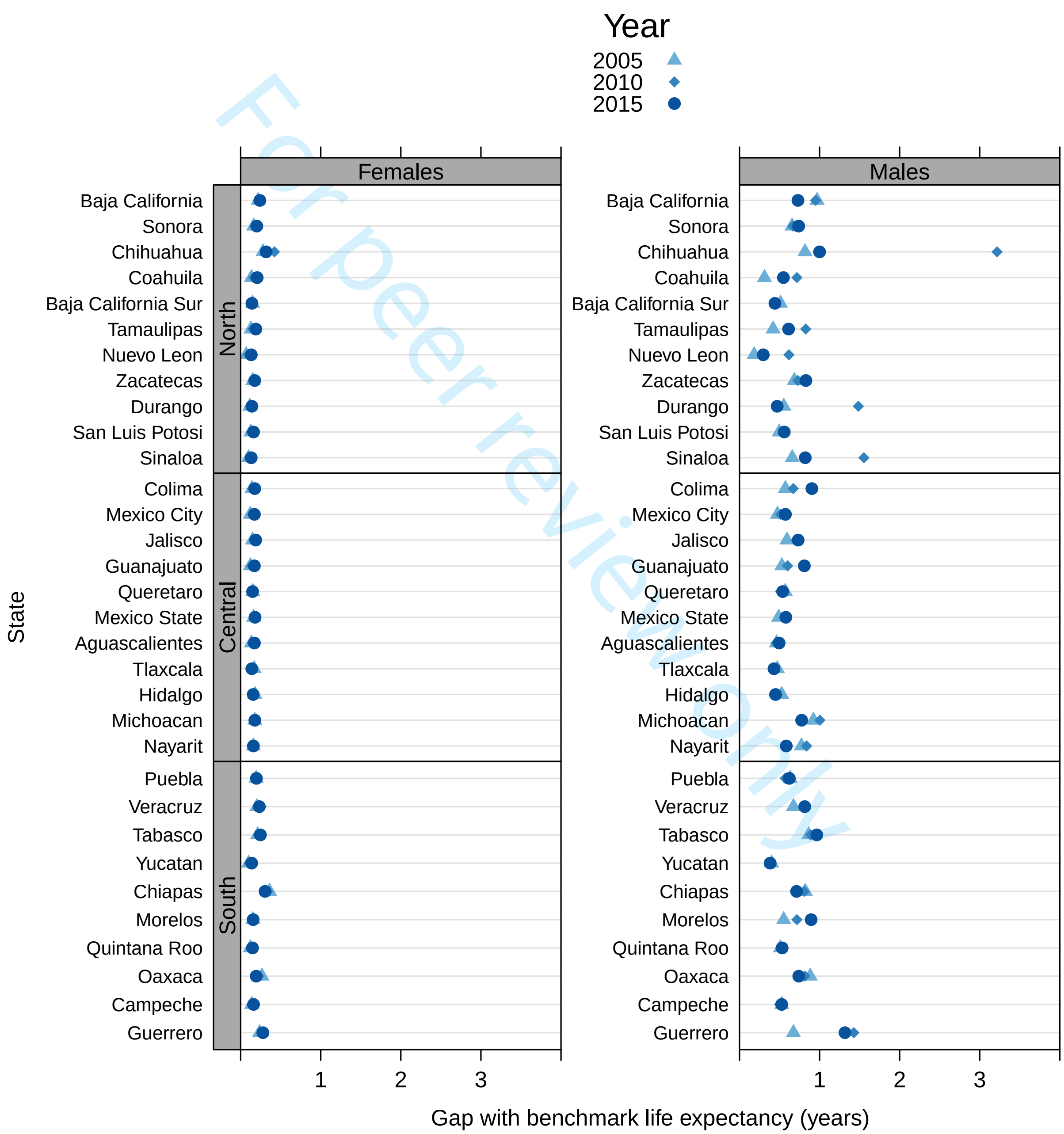


Figure 12: State specific gap with low mortality benchmark for selected years between ages 50-84. Source: own calculations.

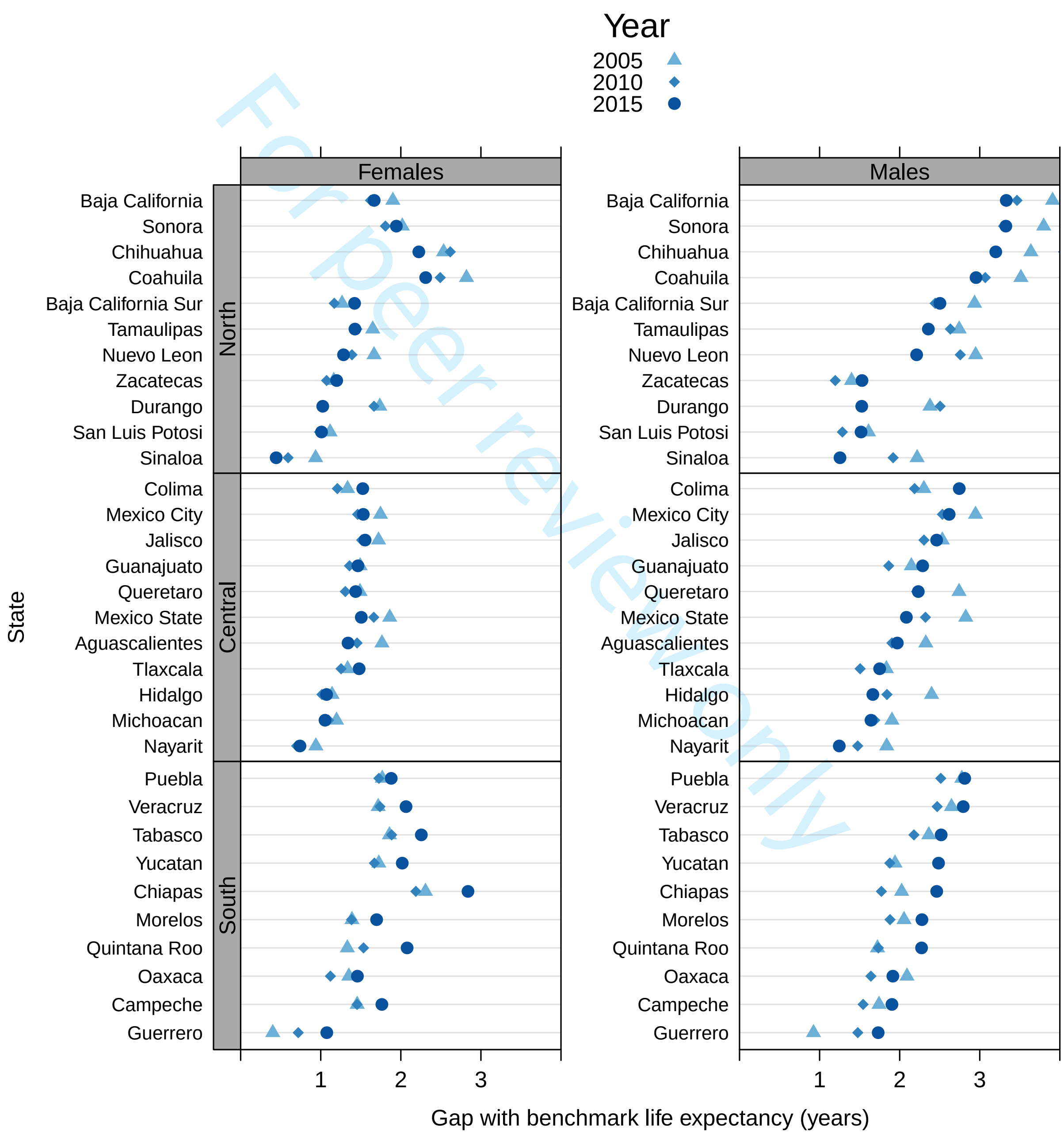


Figure 13: Proportion by cause of death from benchmark mortality for youngest females (ages 0-14). Source: own calculations.

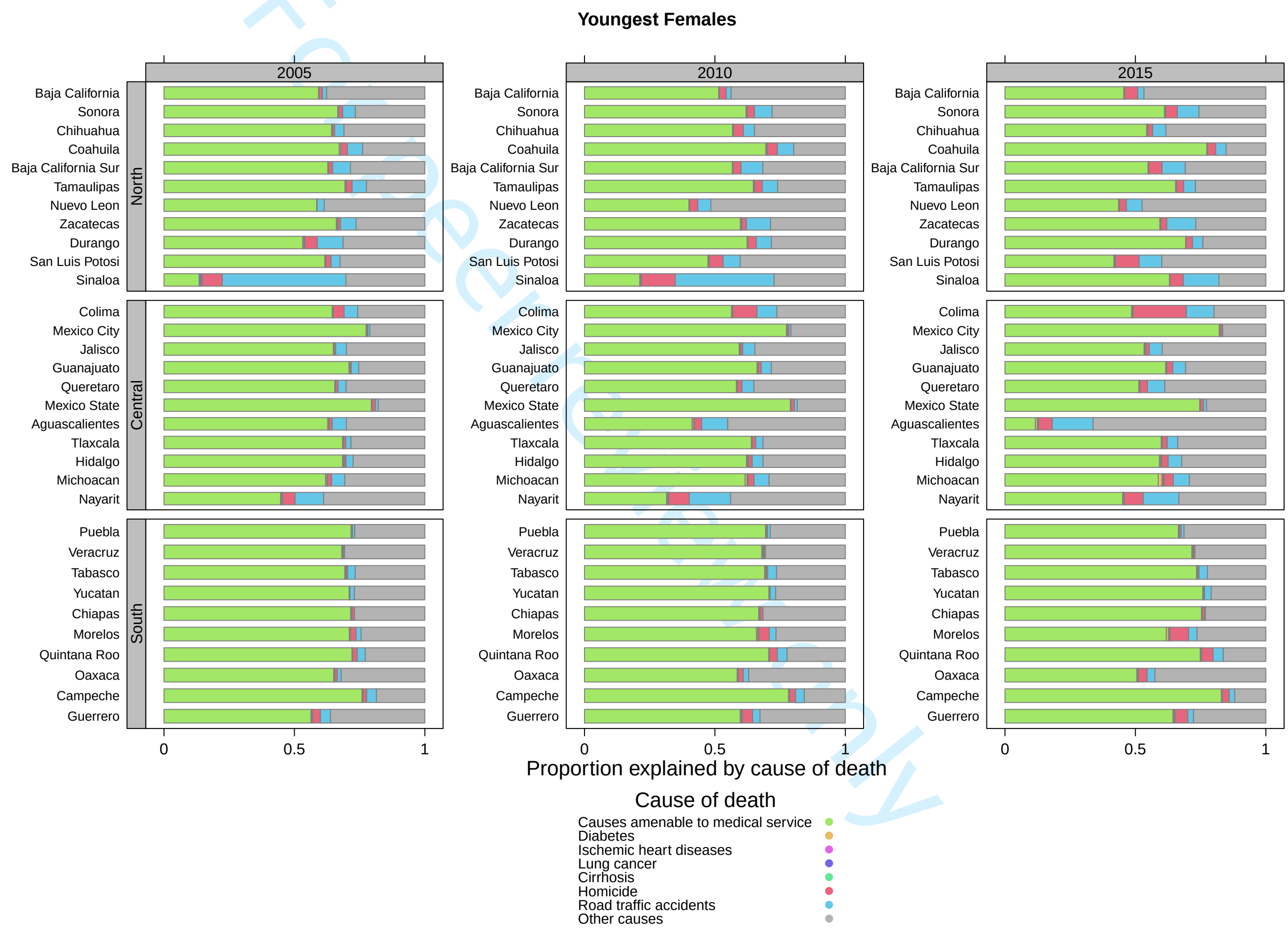


Figure 14: Proportion by cause of death from benchmark mortality for youngest males (ages 0-14). Source: own calculations.

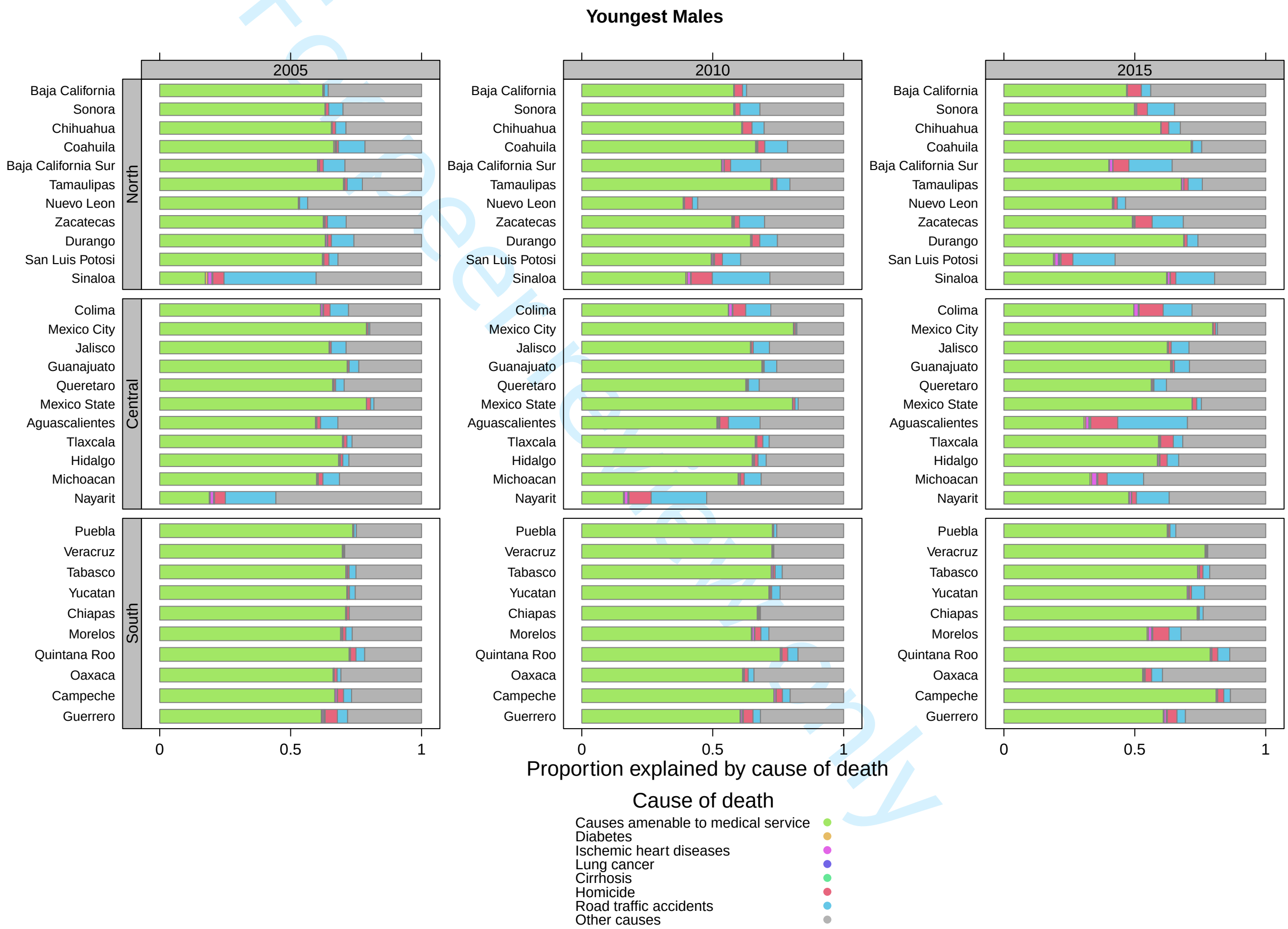


Figure 15: Proportion by cause of death from benchmark mortality for young adult females (ages 15-49). Source: own calculations.

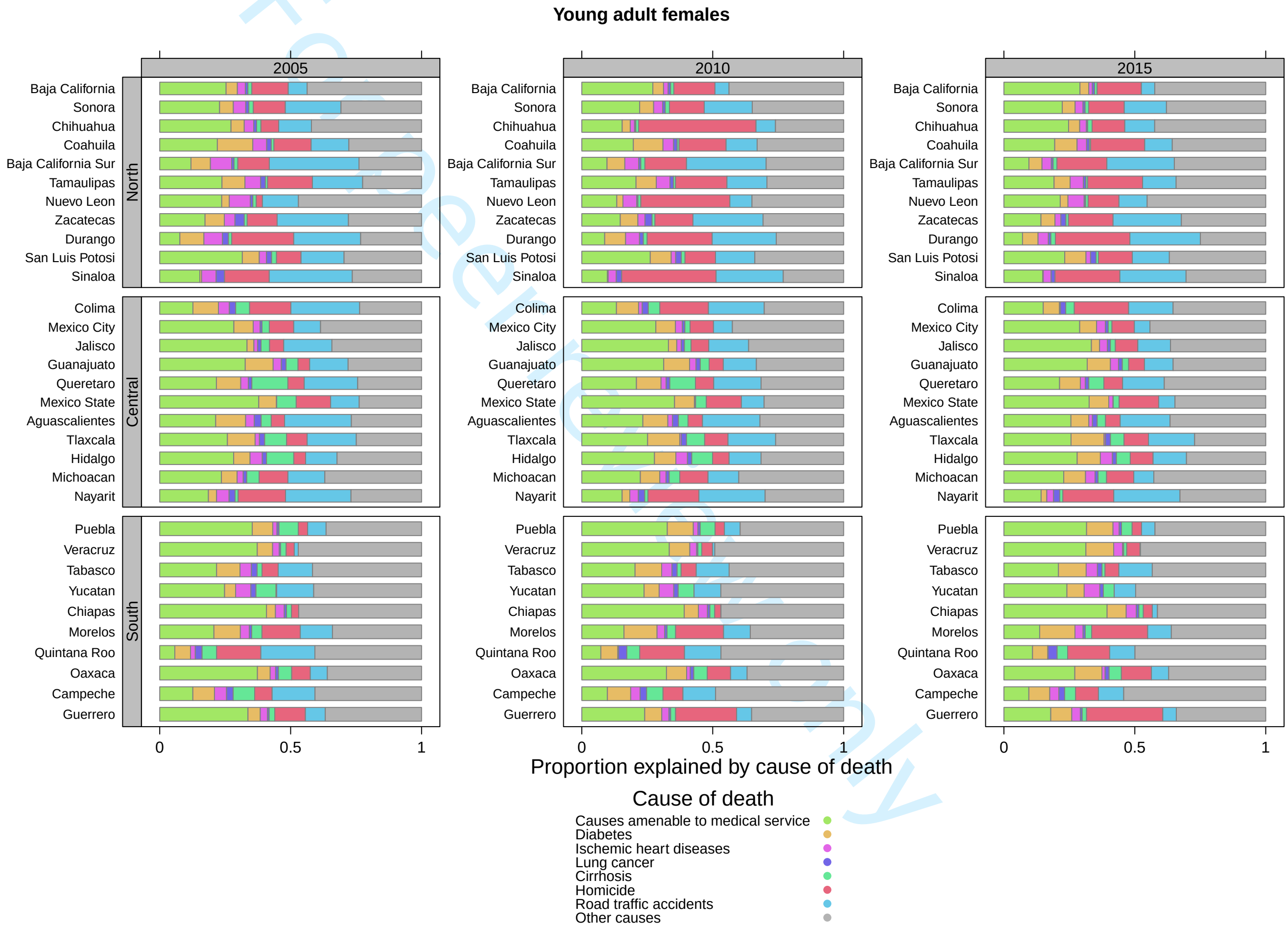


Figure 16: Proportion by cause of death from benchmark mortality for young adult males (ages 15-49). Source: own calculations.

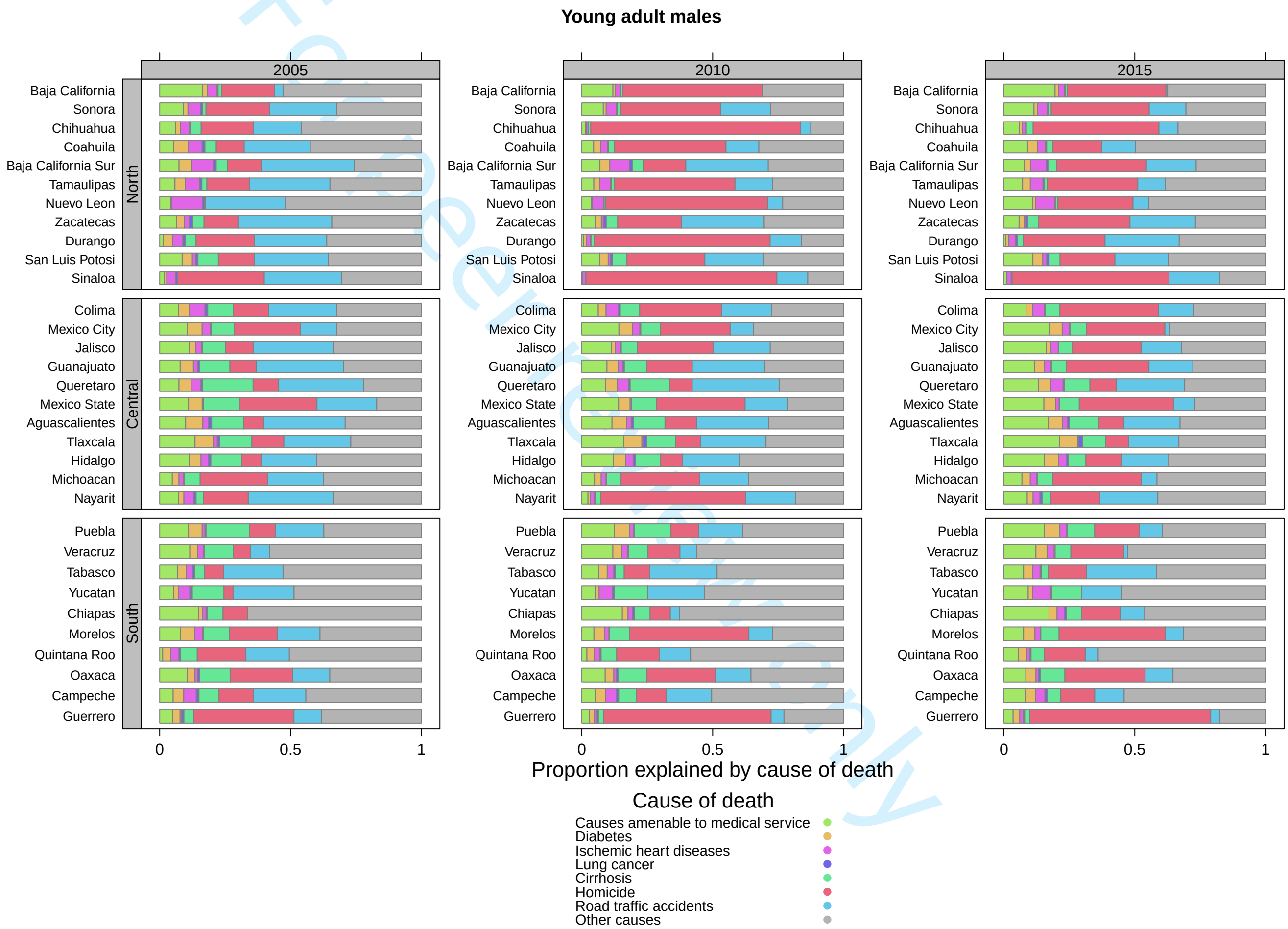


Figure 17: Proportion by cause of death from benchmark mortality for older male adults (ages 50-84). Source: own calculations.

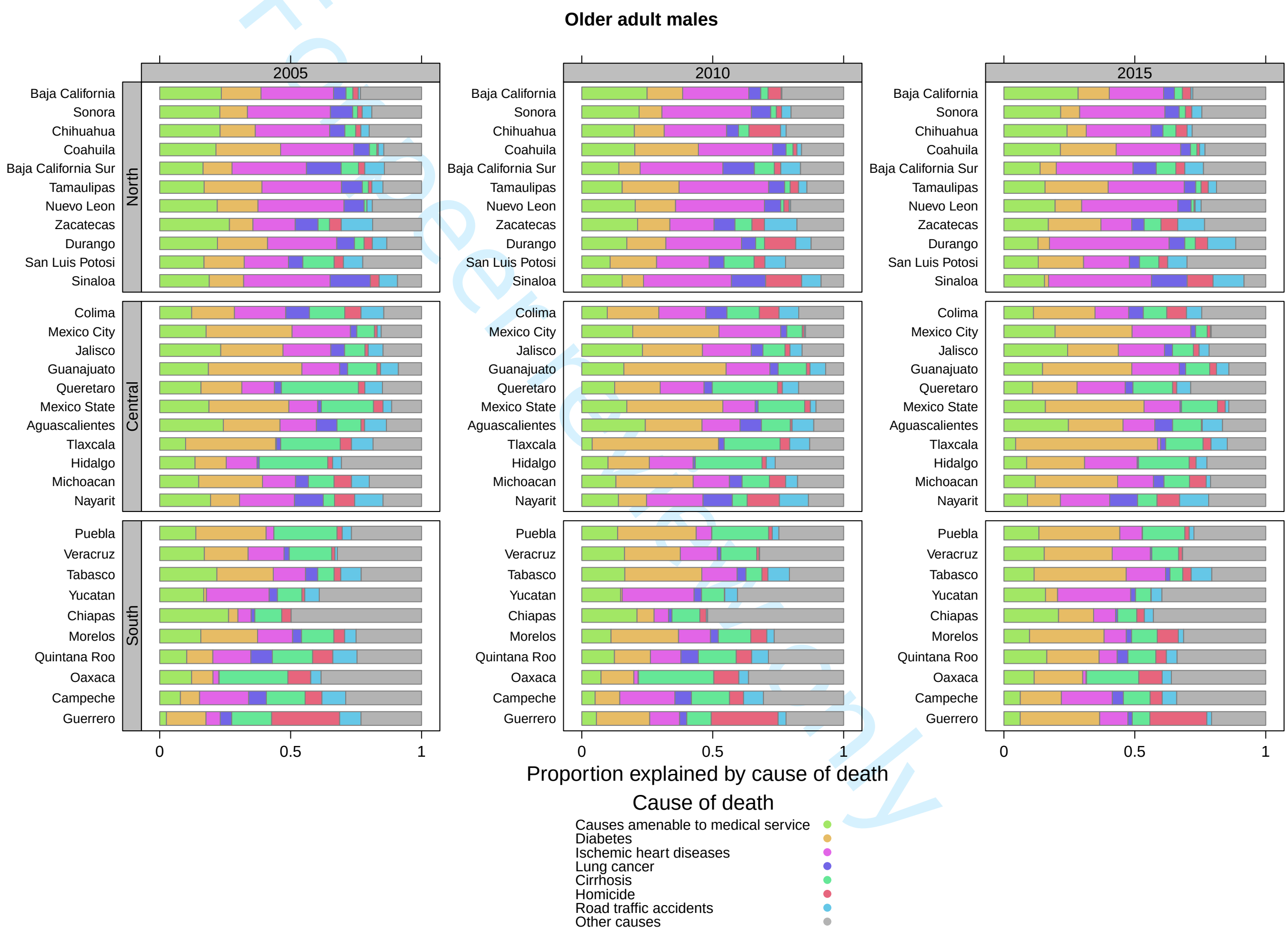
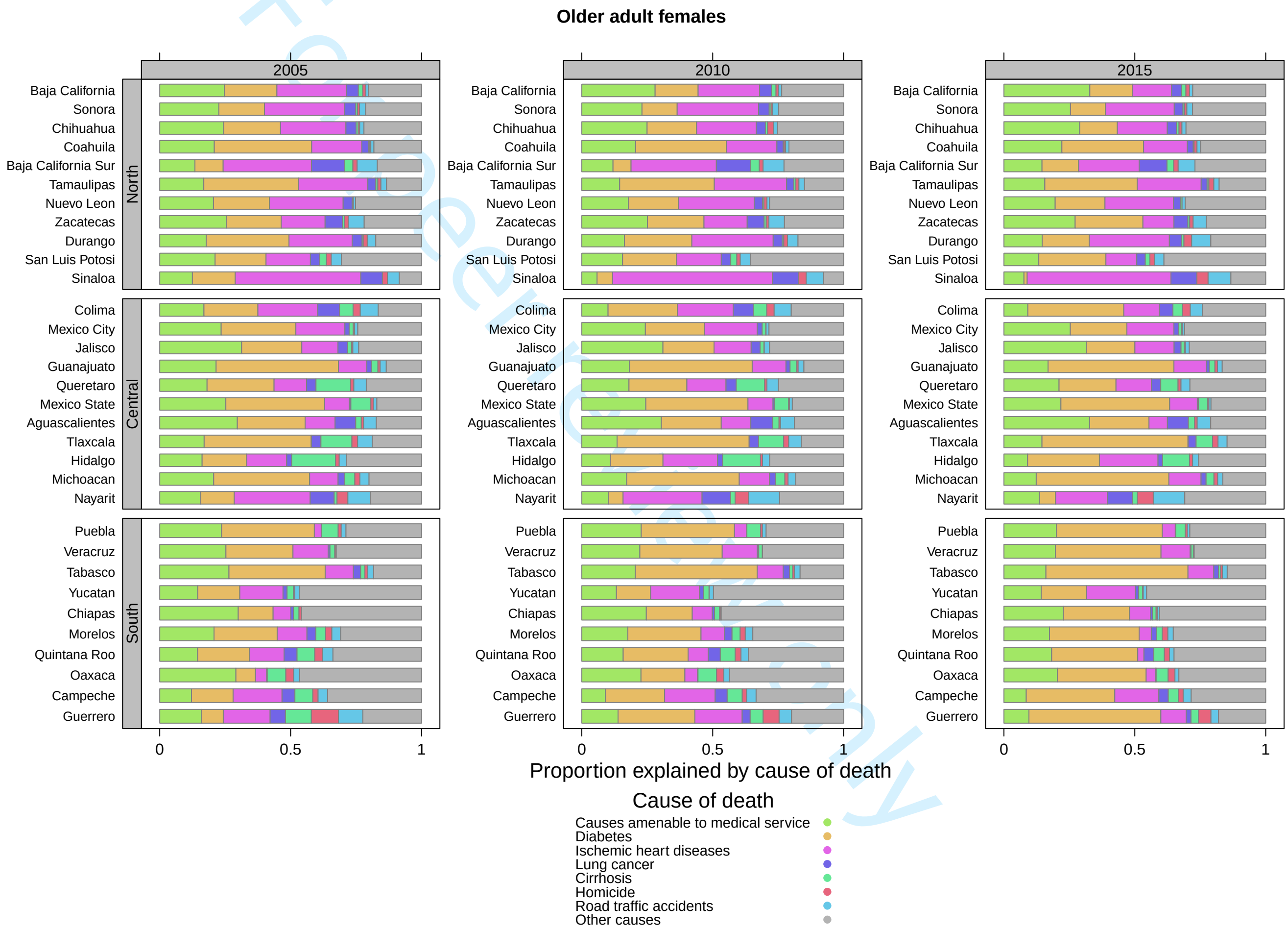


Figure 18: Proportion by cause of death from benchmark mortality for older female adults (ages 50-84). Source: own calculations.



STROBE Statement—Checklist of items that should be included in reports of ***cross-sectional studies***

	Item No	Recommendation
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract **(done, page 1)**
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found **(done, page 2)**
Introduction		
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported **(done, page 3-4)**
Objectives	3	State specific objectives, including any prespecified hypotheses **(done, page 4-5)**
Methods		
Study design	4	Present key elements of study design early in the paper **(done, page 4-6)**
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection **(done, page 5)**
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants **(Not necessary. We work with aggregated data)**
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable **(done, page 6)**
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group **(done, page 5)**
Bias	9	Describe any efforts to address potential sources of bias **(done, page 6)**
Study size	10	Explain how the study size was arrived at **(Not necessary. We work with aggregated data)**
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why **(done, page 5-6)**
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding **(done, page 6-7)**
		(*b*) Describe any methods used to examine subgroups and interactions **(done, page 6-7)**
		(*c*) Explain how missing data were addressed (Not applicable [NA])
		(*d*) If applicable, describe analytical methods taking account of sampling strategy (NA)
		(*e*) Describe any sensitivity analyses **(done, page 5)**
Results		
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed (**Not necessary. We work with aggregated data)**
		(b) Give reasons for non-participation at each stage (**Not necessary. We work with aggregated data)**
		(c) Consider use of a flow diagram (**Not necessary. We work with aggregated data)**
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders **(done, page 5)**
		(b) Indicate number of participants with missing data for each variable of interest

		stage (**Not necessary. We work with aggregated data)**
Outcome data	15*	Report numbers of outcome events or summary measures **(done, pages 7-10)**
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included **(done, page 7-8 and supplemental material)**
		(*b*) Report category boundaries when continuous variables were categorized **(NA)**
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period **(NA)**
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses **(done, page 6-7. 9)**
Discussion		
Key results	18	Summarise key results with reference to study objectives **(done, page 11-14)**
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias **(done, page 13)**
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence **(done, page 13-14)**
Generalisability	21	Discuss the generalisability (external validity) of the study results **(done, page 13-14)**
Other information		
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based **(NA)**

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.