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Uneven state distribution of homicides in Brazil and their effect on life expectancy, 2000–2015: a cross-sectional mortality study

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ABSTRACT

Objective To determine cause-specific and age-specific contributions to life expectancy changes between 2000 and 2015, separately by state and sex in Brazil, with a focus on homicides.

Design Retrospective cross-sectional demographic analysis of mortality.

Setting and population Brazilian population by age, sex and state from 2000 to 2015.

Main outcome measure Using mortality data from the Brazilian Mortality Information System and population estimates from the National Statistics Office, we used death distribution methods and the linear integral decomposition model to estimate levels and changes in life expectancy. We also examine how multiple causes of death, including those attributable to homicides and amenable/avoidable mortality, contributed to these changes from 2000 to 2015.

Results Between 2000 and 2015, life expectancy in Brazil increased from 71.5 to 75.1 years. Despite state-level variation in gains, life expectancy increased in almost all states over this period. However across Brazil, homicide mortality contributed, to varying degrees, to either attenuated or decreased male life expectancy gains. In Alagoas in 2000–2007 and Sergipe in 2007–2015, homicides contributed to a reduction in life expectancy of 1.5 years, offsetting gains achieved through improvements due to medically amenable causes. In the period 2007– 2015, male life expectancy could have been improved by more than half a year in 12 of Brazil's states if homicide mortality had remained at the levels of 2007.

Conclusions Homicide mortality appears to offset life expectancy gains made through recent improvements to mortality amenable to medical services and public health interventions, with considerable subnational heterogeneity in the extent of this phenomenon. Efforts combating the causes of homicides can increase life expectancy beyond what has been achieved in recent decades.

Strengths and limitations of this study

► We examine data from the Mortality Information System and from the National Statistics office from Brazil.

► We employed death distribution methods in order to correct for the lack of completeness towards the beginning of the study period.

► We use the concept of amenable/avoidable mortality to form the basis of the cause of death classifications in our study to complement the analysis of homicide mortality.

adults,[2 3] recent improvements in population health attributable to ongoing public health interventions and pushes towards universal health coverage are in jeopardy.[4–7] On average, Brazilians live 20 years longer than half a century ago.[8] These mortality advancements have been driven largely by improvements in medically amenable mortality, in particular infant and cardiovascular disease mortality, which have accompanied the introduction and expansion of a mandated universal healthcare system.[9 10]

Country-level estimates of life expectancy, estimated at 74.7 years in 2015, mask considerable subnational heterogeneity. For instance, life expectancy in 2000 ranged from 63.2 years in Alagoas to 71.3 years in Santa Catarina (online supplemental figure 1 presents a map of Brazil and its states). In addition, women tend to have higher life expectancy than men in Brazil (78.7 and 71.6, respectively in 2015) and homicide rates among men are approximately 10 times higher.[11] Gains in life expectancy have also varied considerably across the country, driven in part by differential gains in average lifespan attributable to amenable mortality; improvements have ranged between 0.6 and 4.1 years between Brazil's Southeast and Northeast

INTRODUCTION

Violence and homicides in Brazil present a considerable public health challenge.[1] With a risk of mortality from homicides 10 times that of most developed countries and it being the leading cause of death among young

regions, respectively, between 2000 and 2010.[12] The high mortality risk from homicides has the potential to reverse gains in life expectancy, as has been reported in Brazil[13] and other Latin American countries.[1] Despite this, the effect of homicides on changes to life expectancy has not been explored in the Brazilian context at the state level in recent periods of time, despite it being a country with over 60 000 murders reported in 2018.[14] An explanation for the lack of studies investigating this could be that national statistics do not report notable changes in homicide rates in the past decade, however this could be due to the balancing effect of homicide rates simultaneously increasing in some states while decreasing in others. For example, whereas the homicide rate declined in Brasilia between 2007 and 2011, in the same period, homicides have increased by more than 40% in Bahia.[14]

In this study, we aim to examine causes of death considered avoidable/amenable to medical service, with a focus on homicide mortality, and their impact on changes in life expectancy by state for men and women separately in the period 2000–2015. These results will provide information for interventions and planning aimed at reducing the burden of homicides. Specifically, they will communicate potential improvements to life expectancy gains that could be achieved through reducing homicide mortality, in addition to identifying the states in most need of public policy attention to minimise these violence and health disparities.

METHODS

We extracted state-level mortality data by age, sex, year and cause of death from the Mortality Information System produced by the Brazilian Ministry of Health.[15] We obtained state-level population estimates for the years 2000 through 2015 from the National Statistics Office.[16]

Death counts registration was evaluated across states in Brazil with traditional demographic methods known as death distribution methods,[17 18] since there is evidence of under-reporting of death counts and variation in data quality across regions.[19] Over the study period (2000–2015), death counts registration improved to over 90% completeness.[20] The method is based on population dynamics equations and assesses the coverage of deaths in relation to the population and the quality of the declaration of death information. Whenever necessary, the methods provide an adjustment factor that is used to correct death counts registration in each region and obtain an appropriately adjusted estimate of mortality (see online supplemental appendix 1). These methods are commonly used by the United Nations and the Institute of Health Metrics and Evaluation and in several national statistics offices.

Cause of death classification

We use the concept of amenable/avoidable mortality to form the basis of the cause of death classifications in our study to complement the analysis of homicide mortality.

Deaths without information on age at death were distributed proportionally by the observed age profile. The concept of amenable/avoidable mortality refers to deaths that should be absent if both timely and quality healthcare is available below age 75 years.[21] This concept has been successfully employed to link the progress of primary care expansion and reductions in amenable/avoidable mortality in Brazil.[9] More recently the concept has included causes amenable to public health interventions that have been seen to alter health behaviours, for example, lung cancer via smoking reduction or homicides.

Using a cause of death classification system used in similar studies,[22 23] we grouped the causes of death into the following 10 categories based on the International Classification of Diseases 10th revision (ICD-10) (online supplemental table 1): (1) homicides, (2) alcoholic liver disease, (3) diabetes, (4) HIV/AIDS, (5) ischaemic heart diseases (IHD), (6) lung cancer, (7) road traffic accidents, (8) suicides, (9) amenable to medical service (including conditions that could be reduced by primary care, secondary intervention and timely medical care up to age 75 years), and (10) all other causes (residual causes).

Homicides, liver disease, diabetes, HIV/AIDS, IHD, lung cancer and suicide were analysed separately as they are amenable to both health behaviours and medical attention, and pose important public health challenges in Brazil.[24 25] For instance, in 2001 Brazil featured in the top 10 countries ranked by number of suicide deaths.[26] The category capturing causes amenable to medical services (9) is linked to major healthcare interventions that have been implemented in recent decades in Brazil, including the Family Health Program.[9 10 27]

Demographic methods

We calculated age-specific and sex-specific death rates for 5-year age groups with an open-age interval at age 90 years for Brazil's 27 states, and constructed sex-specific period life tables for each year from 2000 to 2015 following standard procedures.[28] National results did not significantly differ from those reported by the United Nations.[8] We calculated age-specific and cause-specific contributions to differences in life expectancy at birth following our classification for each subsequent year using the linear integral decomposition procedure (see online supplemental appendix 2 for detailed explanation)[29] and summed up single-year decompositions in order to obtain the aggregate effect for the specified period. We report results for the periods 2000–2007 and 2007–2015 to have two comparable points in time of the same length. Our estimates refer to the middle of the year, for example, 2000–2007 runs from middle of 2000 to middle of 2007 and 2007–2015 runs from middle of 2007 to middle of 2015. The effects for the period 2000–2015 are simply the sum of the effects of the two periods. All procedures were performed using the R software[30] and are fully reproducible from the
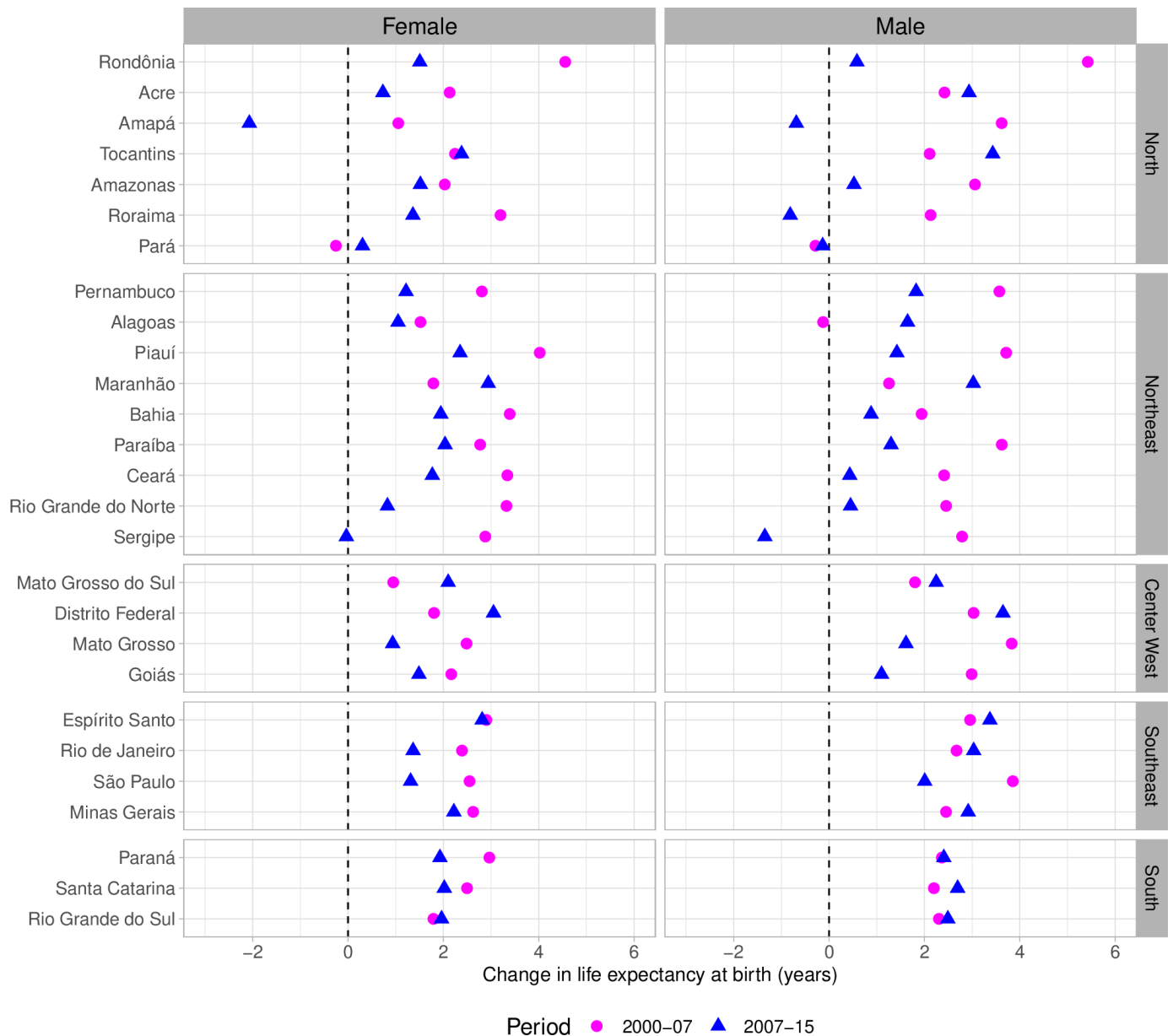
Figure 1 Changes in life expectancy at birth in Brazil (in years), by state and period, from 2000 to 2007 (pink dots) and from 2007 to 2015 (blue triangles). The dashed line at zero represents the situation of no changes in life expectancy over time, whereas dots and triangles to the right (left) of this line correspond to increases (decreases) in life expectancy.

public repository with the data needed at https://github.com/jmaburto/Homicides-and-life-expectancy-in-Brazil.

Patient and public involvement

This study involved secondary data analysis of public sources, thus patients and or the public were not involved in it.

RESULTS

We grouped the Brazilian states within each broad region, and subsequently arranged them in order of the impact of homicides on male life expectancy in 2007–2015 in figures 1–4.

All states, with the exception of Pará, experienced increases in life expectancy for women and men from 2000 to 2007 (figure 1). Relative to the period 2000–2007, in 2007–2015, life expectancy at birth increased at a slower pace among women in 75% of states and among men in 60% of Brazil's states. In four states, life expectancy at birth declined in the latter period among men; among women, life expectancy declined in one state. Despite this overall slowdown, all but four states (Amapá for women, and Amapá, Roraima, Pará and Sergipe for men) showed a continuous increase in life expectancy since 2000. Life expectancy levels for each state and total changes in 2000–2015 are shown in online supplemental table 2.

Figures 2–4 show how homicides, IHD and causes amenable to medical service, respectively, contributed to changes in life expectancy at birth in the periods

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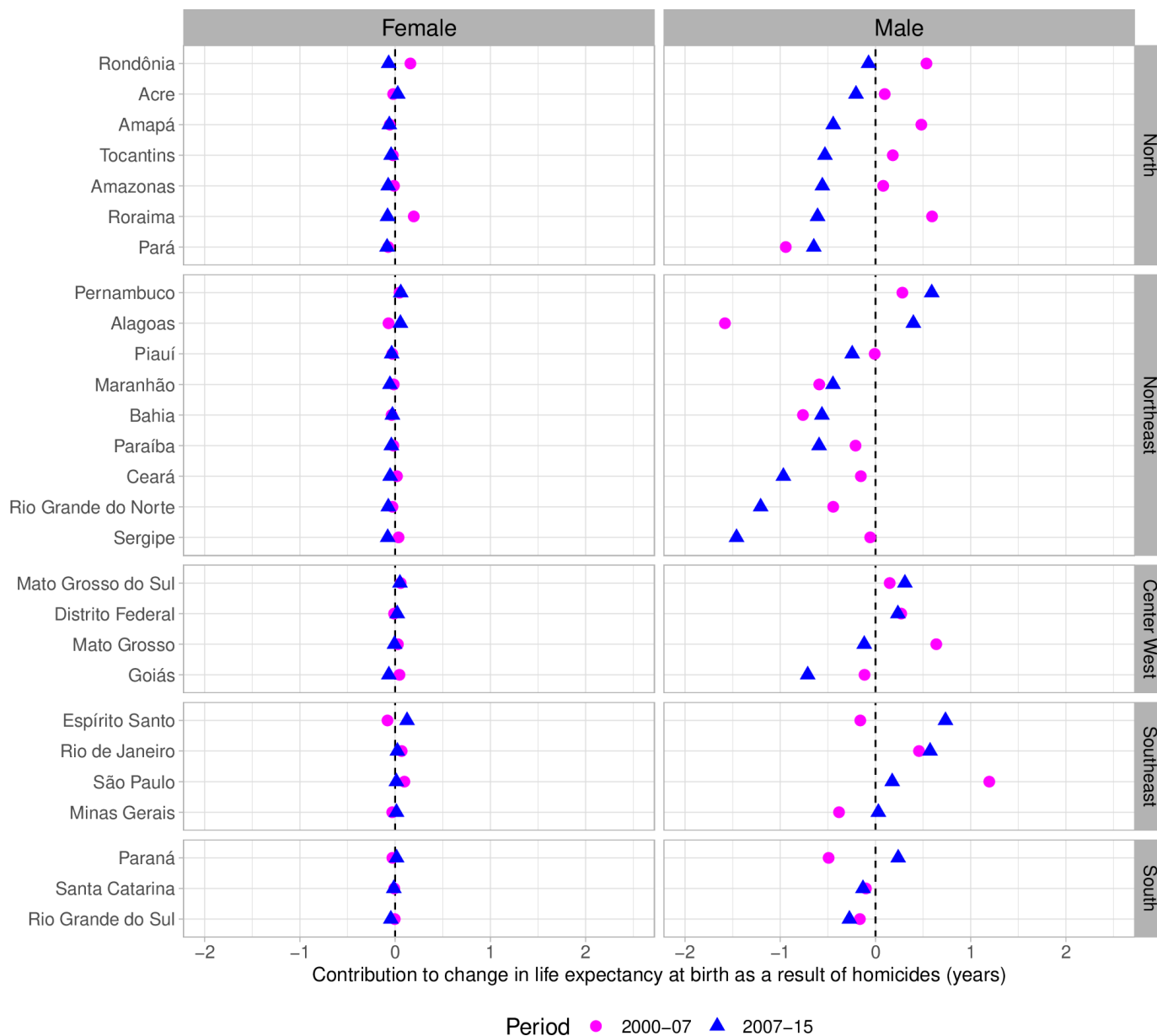
Figure 2 Contribution of homicides to changes in life expectancy at birth in Brazil (in years), by state and period, from 2000 to 2007 (pink dots) and from 2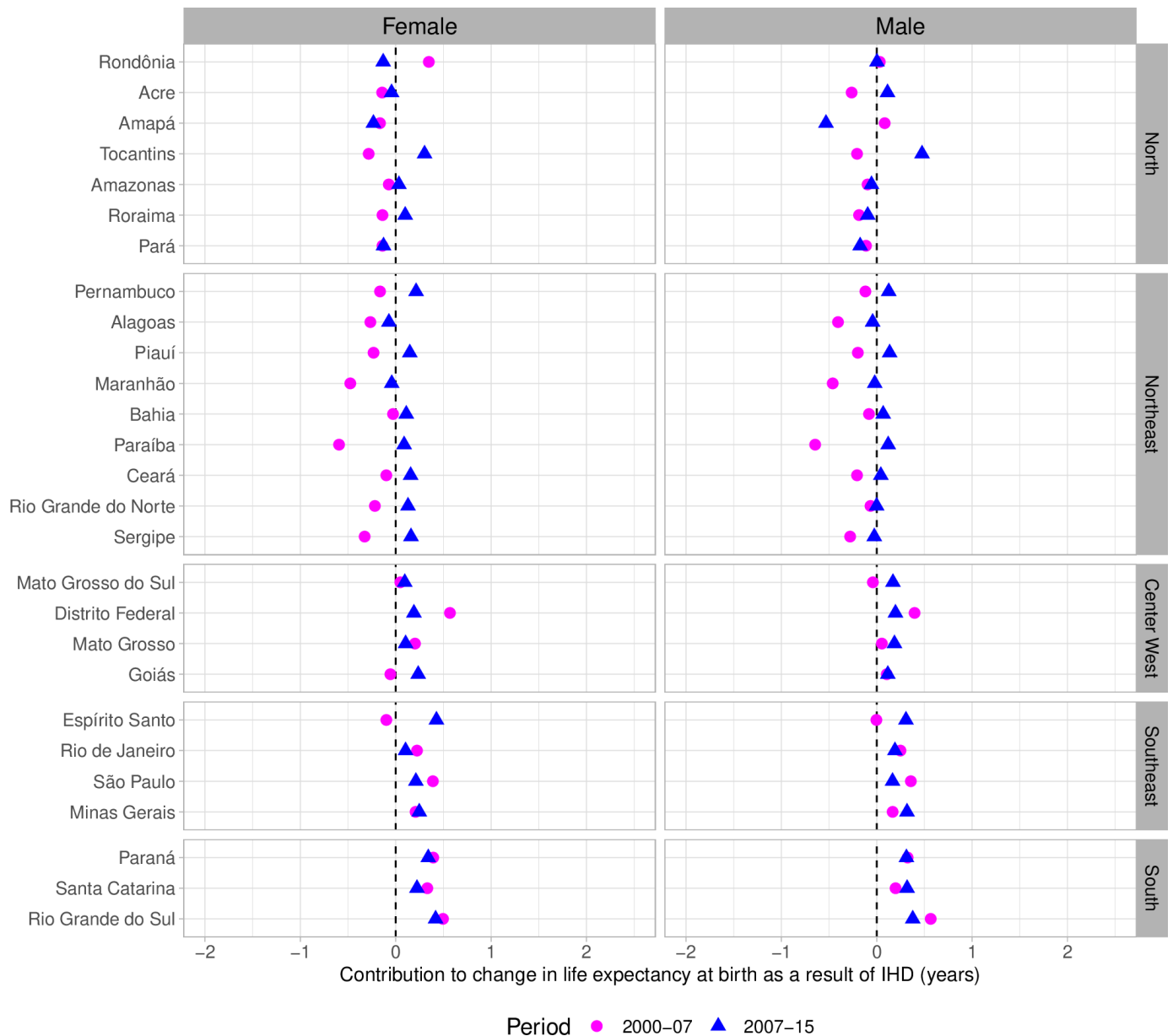007 to 2015 (blue triangles). The dashed line at zero represents the situation of no contribution to changes in life expectancy over time, whereas dots and triangles to the right (left) of this line correspond to increases (decreases) in life expectancy due to changes in homicides.

2000–2007 and 2007–2015 and represent the causes of death from the amenable/avoidable mortality framework that contributed the most to changes in life expectancy at birth in both periods (results for all causes of death, see online supplemental figures 2 and 3).

Homicide mortality increased in 14 states among men in 2000–2007 (figure 2), leading to declines in life expectancy at birth over the period, with especially large contributions in Alagoas state (1.5 years). In 2007–2015 there was a clear worsening in life expectancy in 18 of Brazil's states related to increases in homicide mortality, with three of these states losing one or more years of life expectancy at birth, and 11 losing over 6 months of life on average. Overall, changes in mortality due to homicide

were responsible for the largest declines in life expectancy between 2000 and 2015, compared with other causes. Over the 16-year period, the decline was most marked in the least developed Northeast and Northern regions of Brazil (online supplemental figure 4), including the states of Sergipe, Rio Grande do Norte, Ceará and Pará. The impact of homicides on life expectancy appeared to be restricted to men. As a sensitivity check in online supplemental figure 5, we show results for the periods 2000–2005, 2005–2010, 2010–2015. By breaking the study period into three-time segments it becomes clear that violence dynamics are changing continuously, and that they vary between states and regions. The largest losses in life expectancy were suffered in the last 10 years.

Figure 3 Contribution of ischaemic heart diseases (IHD) to changes in life expectancy at birth in Brazil (in years), by state and period, from 2000 to 2007 (pink dots) and from 2007 to 2015 (blue triangles). The dashed line at zero represents the situation of no contribution to changes in life expectancy over time, whereas dots and triangles to the right (left) of this line correspond to increases (decreases) in life expectancy due to changes in IHD.

Among women and men, 16 states and 15 states, respectively, experienced increases in mortality from IHD in the period 2000–2007, leading to declines in life expectancy.

On the other hand, in 2007–2015 life expectancy due to IHD increased in most states driven by improvements in cause-specific mortality from IHD (21 and 19 states, respectively, among women and men).

Across most states, we found increases in life expectancy due to causes amenable to medical services below age 75 years in both periods. In two states (Acre and Maranhão) we found declines in female life expectancy, while negligible effects on male life expectancy was found in Maranhão state in the period 2000–2007 (figure 4). Notably, between 2000 and 2007, 13 states experienced

increases in female life expectancy of more than 1 year due to medically amenable mortality, whereas this was the case in 12 states among men. Between 2007 and 2015, mortality improvements due to medically amenable causes persisted, although at a slower pace, whereby 18 and 23 states experienced an increased life expectancy by more than 6 months among women and men, respectively, driven by declines in mortality from causes amenable to medical services. Similarly, changes in mortality due to the remaining causes also contributed to increasing life expectancy in most states during the first 15 years of the 21st century (see online supplemental figures 2 and 3).

Although diabetes mortality had a smaller impact on changes in life expectancy relative to other causes of
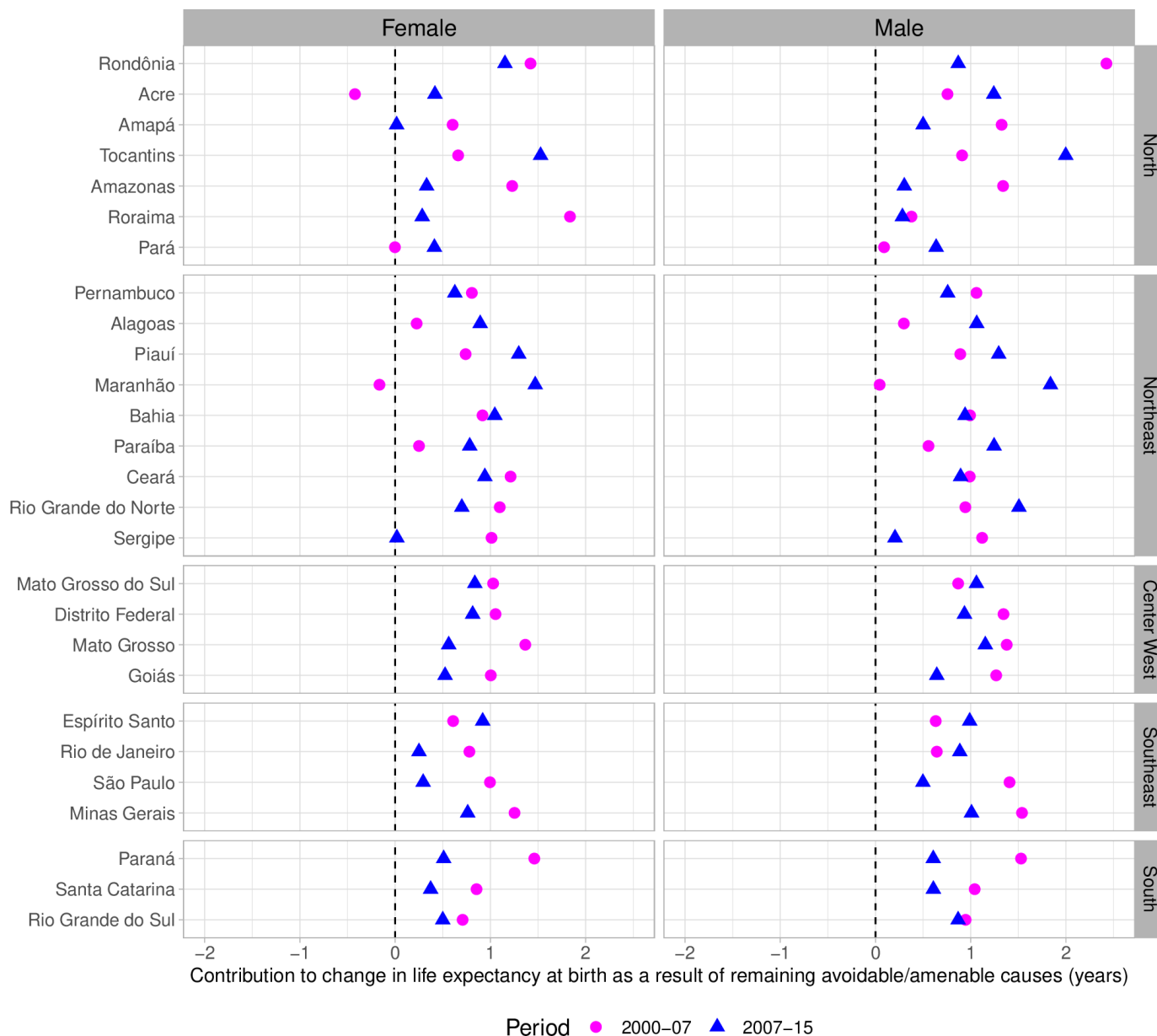
Figure 4 Contribution of causes amenable to medical service to changes in life expectancy at birth in Brazil (in years), by state and period, from 2000 to 2007 (pink dots) and from 2007 to 2015 (blue triangles). The dashed line at zero represents the situation of no contribution to changes in life expectancy over time, whereas dots and triangles to the right (left) of this line correspond to increases (decreases) in life expectancy due to changes in causes amenable to medical service.

death between 2000 and 2015, its impact was considerable in some regions. In the North and Northeast regions, the increase in diabetes mortality led to small decreases in life expectancy between 2000 and 2007, especially among women (online supplemental figure 3). This trend reversed and by 2007–2015, only three states from the Northern region (Amapá, Amazonas and Pará) experienced decreases in female life expectancy. Among men, the impact of diabetes was smaller, however similar to women, was concentrated in the Northern regions of Brazil (online supplemental figure 2).

Contributions to changes in life expectancy due to alcoholic liver disease, HIV/AIDS, lung cancer, suicide and traffic accidents were negligible between 2000 and 2015 (online supplemental figures 2 and 3).

DISCUSSION

The period from 2000 to 2015 marked an increase in the life expectancy at birth in Brazil from 71.5 years to 75.1 years, however the extent of this increase differed between men and women and between Brazil's diverse states. Our findings indicate that potentially large gains in state-specific life expectancy driven by mortality improvements from medically amenable causes were partially offset, at times, by increasing homicide, diabetes and IHD mortality. Brazilian men in

particular have experienced a disproportionately higher homicide burden when compared with women.[11] Had homicide mortality stayed at the same level as at the turn of the century in Brazil's Northern regions, male life expectancy could have increased by at least 6 months in 11 states during the period 2007–2015.

Violence in Brazil

Homicides are unevenly distributed across Brazil's states, leading to slower increases, and in some cases decreases, in male life expectancy. In some instances, increases in homicide mortality have been so drastic that it has driven declines in life expectancy by over 1 year in seven states from the Northeast and North regions (Ceará, Alagoas, Rio Grande do Norte, Bahia, Maranhão, Sergipe and Pará). These states contain eight of the most dangerous cities in the world (Natal, Fortaleza, Belém, Feirá de Santana, Marceió, Vitória de Conquista, Salvador and Aracaju) with homicide rates over 47 deaths per 100 000 people.[31]

Homicides in Brazil are primarily committed with firearms and are related to both drug trafficking, and consumption of drugs and alcohol.[32] Evidence from Brazil suggests that gun control measures can be effective in reducing the burden of violence on population health through specific legislations aiming at firearm disarmament.[33] While we find that such legislations have been effective in some states, in others, particularly in the North and Northeast of Brazil, further state-level efforts aimed at disarmament are encouraged, however the implementation of firearm regulations might be more challenging in these regions.[33] Moreover, the Brazilian government has implemented several measures aiming at reducing violence in the country, such as the National Public Security Force (Força Nacional de Segurança Pública) and the National Public Security Program (Programa Nacional de Segurança Pública com Cidadania).[3] However, there is considerable regional diversity in the success of these government strategies. The most relevant example to this study is the diversity in changes to life expectancy driven by homicide mortality post-strategy implementation, which started in 2004, in the period 2007–2015, with declines in homicide-related life expectancy most prevalent in the North and Northeast (complementary figure from 2004 is shown in online supplemental figure 6).

Evidence suggests that violent death varies considerably by ethnicity, whereby black and ethnically mixed men are at a higher risk of being victims of violent crime.[34 35] In 2007, 55% of the total homicides among men were among mixed race individuals, while 8.2% were among black men. Poverty, social inequality and drug trafficking are important factors determining variation in violent mortality within Brazil's states.[36–38] For example, homicides have increased in regions undergoing an accelerated urbanisation process coupled with slow and unequal economic development.[39] Factors such as poverty, exclusion, and lack of opportunities and safety may encourage violent behaviours. In certain regions, this may lead young people, especially men, to turn to crime as a profitable and economically attractive option,[39] potentially explaining the increase in violence in some states. In

this study, we were unable to disentangle the effect of changes in homicide mortality on life expectancy changes by ethnicity or socioeconomic status within states due to the lack of data disaggregated by these levels for long periods of time.

International context with Latin America

Latin America is currently the region with the highest homicide rates globally.[14] As in Brazil, similar detrimental findings of the effect of violence in life expectancy have been reported in other Latin American contexts.[1] In Mexico, the rise in homicides has led to a stagnation in country-wide life expectancy between 2000 and 2010,[40 41] with significant subnational variation,[22] and was identified as a primary determinant of lifespan inequalities.[42] Another study in Venezuela found that an increase in firearm-related deaths led to life expectancy stagnation in 1996–2013.[43] In Colombia, although homicides have decreased over the last decade, they still represent a large share of total mortality (around 5%), which is estimated to cause a loss of life expectancy of 2.2 and 0.2 years for men and women, respectively.[44] Similar evidence from Brazil at the national level showed that life expectancy could improve 1.5 years for men if homicides were eliminated.[45] Other studies report evidence of further adverse impacts of violence on population health beyond mortality and decreases in life expectancy. For example, mental health and perception of vulnerability in contexts of increasing homicide mortality are often unquantifiable.[46] Consequently, health systems should be prepared for a future increase in mental health issues due to potential insecurity felt by Brazilians. In light of this, further studies into the population health burden of homicides, beyond just mortality, across Brazil's states are encouraged.

Other causes of death

The period 2000–2007 also saw increases in mortality from IHD, again offsetting rising life expectancy due to improvements in mortality from other medically amenable causes, and again mostly concentrated in Brazil's Northern states. Additionally, some Northern states saw increases in diabetes mortality over the same period, primarily affecting women. On the other hand, in the period 2007–2015, improvements in mortality from IHD and diabetes led to increases in life expectancy among women and men in most states. The extent of subnational variation in the impact of homicides, IHD and diabetes-related mortality on life expectancy at birth, with a considerably high burden in Northern states, demonstrates the persistence of health inequalities in Brazil.[32]

Medically amenable mortality contributed significantly to increasing life expectancy throughout the period from 2000 to 2015. Although in two states, Acre and Maranhão, mortality from amenable causes of death deteriorated between 2000 and 2007, these states recovered and improved life expectancy by reducing mortality attributable to medically amenable causes in 2007–2015. Our results mirror findings reported in similar studies. Previous evidence suggests that improvements in primary healthcare have played an essential role in reducing deaths amenable to healthcare in Brazil.[9 47] Similarly, our study highlights the importance of building a strong healthcare system in the Northern regions

to further reduce IHD-related mortality. Comprehensive and community-based health interventions can contribute to further decrease mortality from IHD in areas with high prevalence through a combination of measures focused on prevention, healthcare and follow-up for heart diseases.[25]

Strengths and limitations

The analysis has several limitations. First, Brazilian mortality data were still considered 'incomplete' according to the Pan American Health Organization's criteria despite improvements in death counts coverage, particularly regarding certificate completeness and age reporting.[48] To address this, we used death estimates corrected for completeness based on indirect demographic methods (see online supplemental appendix 1).[26] Additionally, we used 5-year age groups to avoid age-heaping bias and applied death distribution methods in age groups with low rates of migration to minimise the effect of migration on our estimates.[20] Second, causes of death could have been misclassified. To minimise chances of misclassification, we used broad cause of death categories that uses the concept of avoidable/amenable mortality and used data from 2000 onwards, using only the ICD-10 classification. In addition, some groups of causes are not consistent between states. For example, the group Y87 (deaths due to the sequelae of suicides and homicides) cannot be disaggregated for all the states in Brazil to attribute a share to homicides. The impact that this might have on our results, however, is negligible as deaths classified with this group represent only 0.009% of the total deaths. Finally, the concept of amenable mortality is not able to allude to differences in the effectiveness of healthcare interventions over time and between states.[49 50] In addition, the Brazilian Ministry of Health restricts classification of causes amenable to medical services up to age 75 years, a common practice when classifying avoidable mortality.[50] To ensure comparability, we did not consider causes of death amenable to medical service above age 75 years.

CONCLUSION AND FUTURE DIRECTIONS

There is a need for increased attention and approaches to violence as a public health problem. During the health transition, the emphasis of healthcare shifted from acute to chronic care without incorporating violence as a dimension of healthcare. Latin America, including Brazil, is currently the region with the highest homicide rates globally.[14] Homicide mortality in Latin American countries is strongly associated with political instability, economic inequality, social segregation and drug trafficking. We show that in Brazil there is a need for state-specific interventions to change the cultural, economic and social conditions associated with risk factors that trigger the surge of violence.

The gains made in reducing mortality attributable to causes amenable to medical services in Brazil are the primary driver of increases in life expectancy, however homicide mortality offsets this increase by over half a year in 12 states. This subnational heterogeneity within Brazil mirrors the diversity found across many Latin American countries. Homicide mortality is a local problem, however one that is a pertinent public health issue across the region, and which continues to inhibit progress towards longer and healthier lives. Better data collection is needed to accurately assess the effects of mortality from homicides on life expectancy by subpopulations, including within states.

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**Supplementary material for the paper "The uneven state-distribution of homicides in
Brazil and their effect on life expectancy, 2000-15"**

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Section 1. Death Distribution Methods summary

The first step of the study is to assess the quality and adjust the mortality data from states in Brazil. This analysis is done using a series of traditional demographic methods, better known as Death Distribution Methods (Hill, 2017; Hill, You and Choi, 2009). These methods were developed, based on population dynamics equations, to assess the coverage of deaths in relation to the population and the quality of the declaration of information on deaths and population. The methods compare the distribution of deaths by age with the age distribution of the population and provide the age pattern of mortality for a defined period (Hill, 2017; Murray, et.al, 2010; Hill, You and Choi, 2009). There are three main varians for evaluating the quality of mortality data: general growth balance (GGB), synthetic extinct generation (SEG) and the adjusted synthetic extinct generations (SEG-adj). The methods have very strong assumptions: population is closed to migration or subject to very small migration flows, the degree of coverage of deaths is constant by age, the degree of coverage of the population counts is constant by age, and the ages of the living and of deaths are declared without errors. Queiroz, et.al (2020) provides an detailed description of the methods and discuss their applications in different scenarios.

GGB is derived from the basic demographic equilibrium equation, which defines the rate of population growth as the difference between the rate of entry and the rate of exit of the population. This relationship, according to Hill (1987), also occurs for any age segment with open interval x +, and the entries occur as birthdays at ages x. Thus, the difference between the entry rate x + and the population growth rate x + produces a residual estimate of the mortality rate x + (Hill, 1987; Hill, You and Choi, 2009). If the residual mortality estimate can be estimated from two population censuses, and compared with a direct mortality estimate using the death registry, the degree of coverage of the death registry can be estimated and mortality data adjusted (Hill, 1987; Hill, You and Choi, 2009; Murray, et.al, 2010).

SEG uses age-specific growth rates to convert an age distribution of deaths into an age distribution of a population. In a stationary population the deaths observed after a certain age x are equal to the population over the same age x, we have that the deaths of a population over age x provide an estimate of the population over the same age. Age-specific population growth rates are used to adjust the number of deaths in the stationary population for an unstable population. The sum of the number of deaths over age x gives an estimate of the population over age x. The degree of coverage of the death record will be given by the ratio between the deaths estimated by the population above age x and the population observed above age x.

Hill, You and Choi (2009) suggest a combination of the methods of GGB and SEG that can be more robust than the application of the two methods separately. The adjusted method consists of applying the GGB to obtain estimates of the change in census coverage, and using that estimate to adjust one of the demographic censuses (population enumeration) and then apply SEG method with the adjusted population to obtain the degree of coverage of the mortality data.

Although they have some limitations, DDMs provide very robust and consistent results for a series of applications across the globe. For instance, Peralta et al., 2019 applied the methods to evaluate data quality at the sub-national level in Ecuador. Glei, Barbieri and Santamaria-Ulloa (2019) studied the quality of mortality estimates in Costa Rica and compared to other estimates. Wang et al. (2016) shows the application of DDM as part of the procedures of the Global Burden of Diseases and Lima and Queiroz (2014) and Queiroz, et.al (2020) evaluate quality of mortality information for small-areas in Brazil overtime.

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Supplementary material for the paper "The uneven state-distribution of homicides in Brazil and their effect on life expectancy, 2000-15"

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Section 2. Decomposition method summary

The decomposition method used in this paper is based on the line integral model (Horiuchi et al 2008). Suppose f (e.g. $e^\dagger$ or life expectancy) is a differentiable function of n covariates (e.g. each age-cause specific mortality rate) denoted by the vector $A = [x_1, x_2, \ldots, x_n]^T$. Assume that f and A depend on the underlying dimension t, which is time in this case, and that we have observations available in two time points t_1 and t_2. Assuming that A is a differentiable function of t between t_1 and t_2, the difference in f between t_1 and t_2 can be expressed as follows:

$$f_2 - f_1 = \sum_{i=1}^{n} \int_{x_i(t_1)}^{x_i(t_2)} \frac{\partial f}{\partial x_i} dx_i = \sum_{i=1}^{n} c_i, \qquad (2)$$

where c_i is the total change in f (e.g. $e^\dagger$ or life expectancy) produced by changes in the ith covariate, x_i. The c_i's in equation (2) were computed with 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.

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Appendix Table 1. ICD Codes for the classification of avoidable/amenable morta

Cause	code	descrition
Homicide	X85	Assault by drugs, medicaments, and biological substan
	X86	Assault by corrosive substance
	X87	Assault by pesticides
	X88	Assault by gases and vapors
	X89	Assault by other specified chemicals and noxious substances
	X90	Assault by unspecified chemical or noxious substance
	X91	Assault by hanging, strangulation, and suffocation
	X92	Assault by drowning and submersion
	X93	Assault by handgun discharge
	X94	Assault by rifle, shotgun, and larger firearm discharge
	X95	Assault by other and unspecified firearm discharge
	X96	Assault by explosive material
	X97	Assault by smoke, fire, and flames
	X98	Assault by steam, hot vapors, and hot objects
	X99	Assault by sharp object
	Y00	Assault by blunt object
	Y01	Assault by pushing from high place
	Y02	Assault by pushing or placing victim before moving object
	Y03	Assault by crashing of motor vehicle
	Y04	Assault by bodily force
	Y05	Sexual assault by bodily force
	Y06	Neglect and abandonment
	Y07	Other maltreatment syndromes
	Y08	Assault by other specified means
	Y09	Assault by unspecified means

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Suicide and self-inflicted injuries	X60	Intentional self-poisoning by and exposure to nonopio analgesics, antipyretics, and antirheumatics
	X61	Intentional self-poisoning by and exposure to antiepileptic, sedative-hypnotic, antiparkinsonism, and psychotropic drugs, not elsewhere classified
	X62	Intentional self-poisoning by and exposure to narcotic and psychodysleptics [hallucinogens], not elsewhere classified
	X63	Intentional self-poisoning by and exposure to other dr acting on the autonomic nervous system
	X64	Intentional self-poisoning by and exposure to other an unspecified drugs, medicaments, and biological substances
	X65	Intentional self-poisoning by and exposure to alcohol
	X66	Intentional self-poisoning by and exposure to organic solvents and halogenated hydrocarbons and their vapo
	X67	Intentional self-poisoning by and exposure to other ga and vapors
	X68	Intentional self-poisoning by and exposure to pesticid
	X69	Intentional self-poisoning by and exposure to other an unspecified chemicals and noxious substances
	X70	Intentional self harm by hanging, strangulation, and suffocation
	X71	Intentional self harm by drowning and submersion
	X72	Intentional self harm by handgun discharge
	X73	Intentional self harm by rifle, shotgun, and larger firea discharge
	X74	Intentional self harm by other and unspecified firearm discharge
	X75	Intentional self harm by explosive material
	X76	Intentional self harm by smoke, fire, and flames

	X77	Intentional self harm by steam, hot vapors, and hot objects
	X78	Intentional self harm by sharp object
	X79	Intentional self harm by blunt object
	X80	Intentional self harm by jumping from a high place
	X81	Intentional self harm by jumping or lying before movi object
	X82	Intentional self harm by crashing of motor vehicle
	X83	Intentional self harm by other specified means
	X84	Intentional self harm by unspecified means
HIV/AIDS	B20	Human immunodeficiency virus [HIV] disease resultin in infectious and parasitic diseases
	B21	Human immunodeficiency virus [HIV] disease resultin in malignant neoplasms
	B22	Human immunodeficiency virus [HIV] disease resultin in other specified diseases
	B23	Human immunodeficiency virus [HIV] disease resultin in other conditions
	B24	Unspecified human immunodeficiency virus [HIV] disease
Ischemic heart diseases	I20	Angina pectoris
	I21	Acute myocardial infarction
	I22	Subsequent ST elevation (STEMI) and non-ST elevati (NSTEMI) myocardial infarction
	I23	Certain current complications following ST elevation (STEMI) and non-ST elevation (NSTEMI) myocardial infarction
	I24	Other acute ischemic heart diseases
	I25	Chronic ischemic heart disease
Lung cancer	C34	Malignant neoplasm of bronchus and lung
Diabetes	E10	Insulin-dependent diabetes mellitus
	E11	Noninsulin-dependent diabetes mellitus

	E12	Malnutrition-related diabetes mellitus
	E13	Other specified diabetes mellitus
	E14	Unspecified diabetes mellitus
Road traffic acidentes	V00-V09	Pedestrian injured in transport accident
	V10-V19	Pedal cycle rider injured in transport accident
	V20-V29	Motorcycle rider injured in transport accident
	V30-V39	Occupant of three-wheeled motor vehicle injured in transport accident
	V40-V49	Car occupant injured in transport accident
	V50-V59	Occupant of pick-up truck or van injured in transport accident
	V60-V69	Occupant of heavy transport vehicle injured in transpo accident
	V70-V79	Bus occupant injured in transport accident
	V80-V89	Other land transport accidents
Alcoholic liver disease	K70	Alcoholic liver disease
Avoidable causes of deaths due to interventions of the Brazilian Health System		See Malta et al (2007) and Malta et al. (2010)

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Appendix Table 2. Life expectancy estimates for Brazilian states.

Region	State	Females				Males			
		2000	2007	2015	Increase 2000-15	2000	2007	2015	Increa
Center West	Distrito Federal	76.4	78.2	81.3	4.9	68.0	71.1	74.7	
	Goiás	73.7	75.9	77.4	3.7	66.4	69.4	70.5	
	Mato Grosso	73.6	76.1	77.0	3.4	65.3	69.1	70.7	
	Mato Grosso do Sul	75.2	76.2	78.3	3.0	67.8	69.6	71.8	
North	Acre	72.6	74.7	75.5	2.9	65.6	68.0	71.0	
	Amapá	75.9	77.0	74.9	-1.0	65.5	69.1	68.5	
	Amazonas	73.5	75.5	77.0	3.5	66.7	69.8	70.3	
	Pará	75.2	74.9	75.2	0.1	68.5	68.2	68.1	
	Rondônia	71.6	76.1	77.6	6.1	64.5	69.9	70.5	
	Roraima	71.5	74.7	76.0	4.6	65.7	67.9	67.0	
	Tocantins	72.3	74.5	76.9	4.6	66.8	68.9	72.3	
Northeast	Alagoas	73.3	74.8	75.9	2.6	67.2	67.0	68.7	
	Bahia	73.3	76.7	78.7	5.3	68.4	70.4	71.2	
	Ceará	73.5	76.8	78.6	5.1	67.8	70.2	70.7	
	Maranhão	71.5	73.3	76.2	4.7	66.5	67.8	70.8	
	Paraíba	73.4	76.2	78.2	4.8	65.8	69.4	70.7	
	Pernambuco	72.9	75.7	76.9	4.0	63.9	67.5	69.3	
	Piauí	71.4	75.4	77.8	6.4	65.4	69.1	70.5	
	Rio Grande do Norte	74.4	77.7	78.5	4.1	68.5	71.0	71.4	
	Sergipe	73.9	76.8	76.7	2.8	67.2	70.0	68.7	
South	Paraná	74.1	77.0	79.0	4.9	67.6	70.0	72.4	
	Rio Grande do Sul	76.0	77.8	79.7	3.8	67.9	70.2	72.7	
	Santa Catarina	75.9	78.4	80.4	4.5	68.9	71.1	73.8	
Southeast	Espírito Santo	74.5	77.4	80.3	5.7	66.5	69.5	72.8	
	Minas Gerais	74.7	77.3	79.6	4.8	67.7	70.2	73.1	
	Rio de Janeiro	73.9	76.3	77.6	3.8	64.8	67.5	70.5	
	São Paulo	75.4	78.0	79.3	3.9	66.9	70.8	72.8	

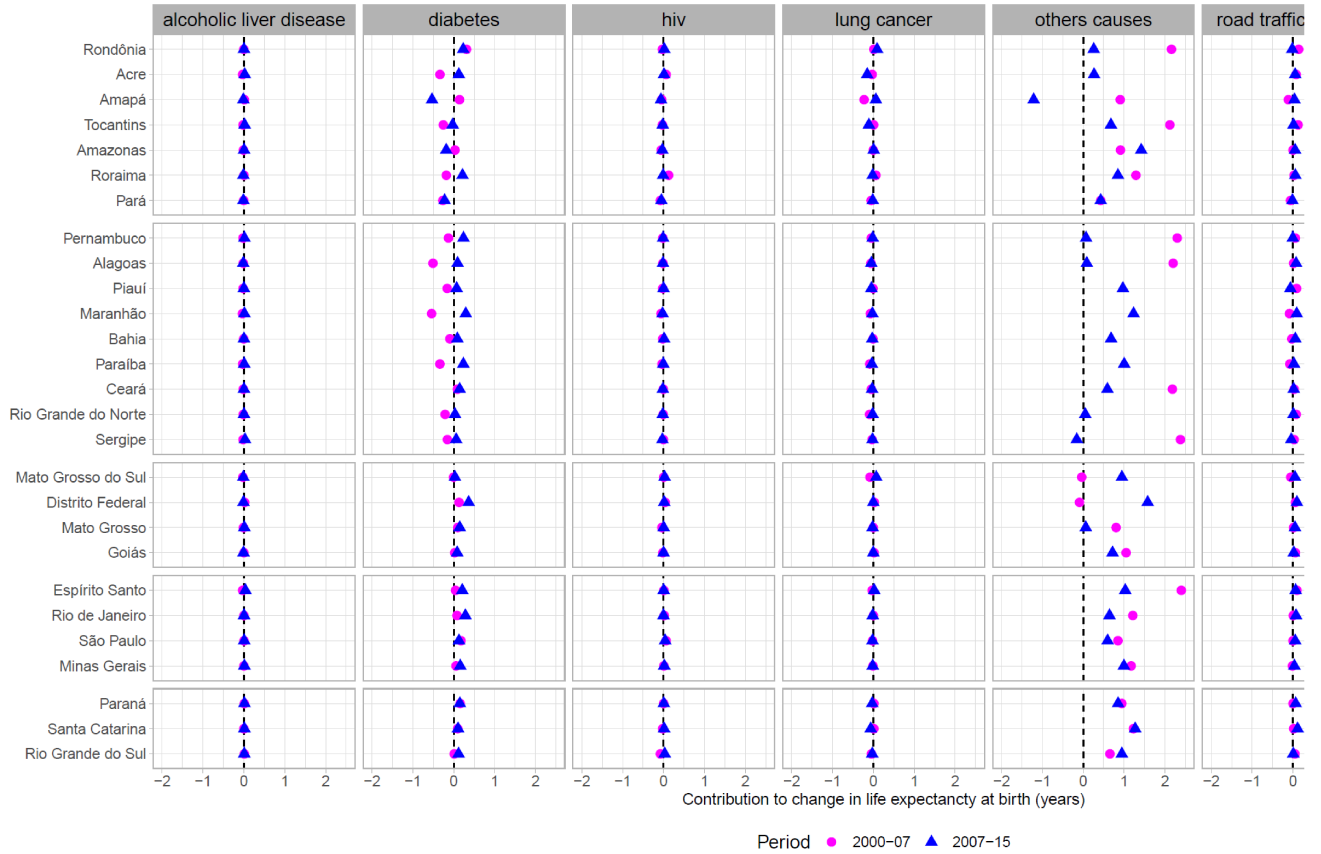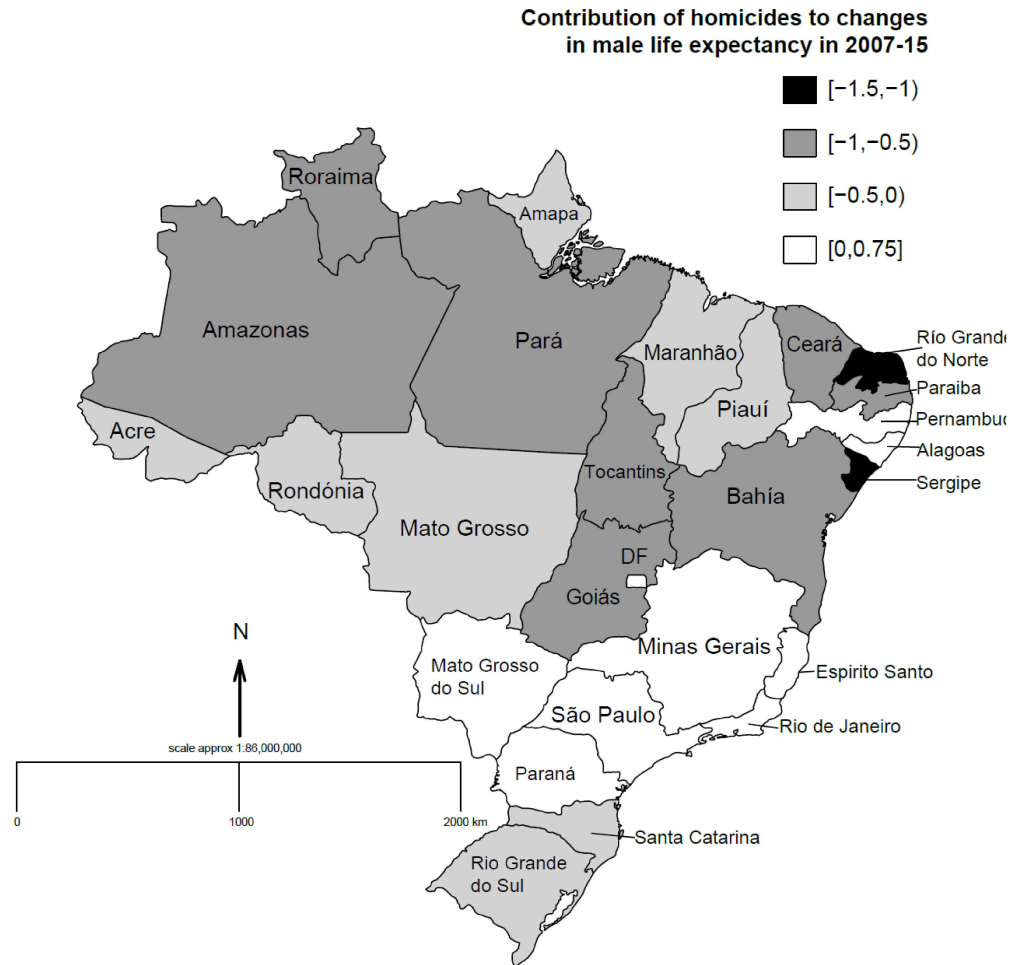**Figure S1. Map of states in Brazil.**

**Figure S2. Cause specific contributions to changes in male life expectancy by s**
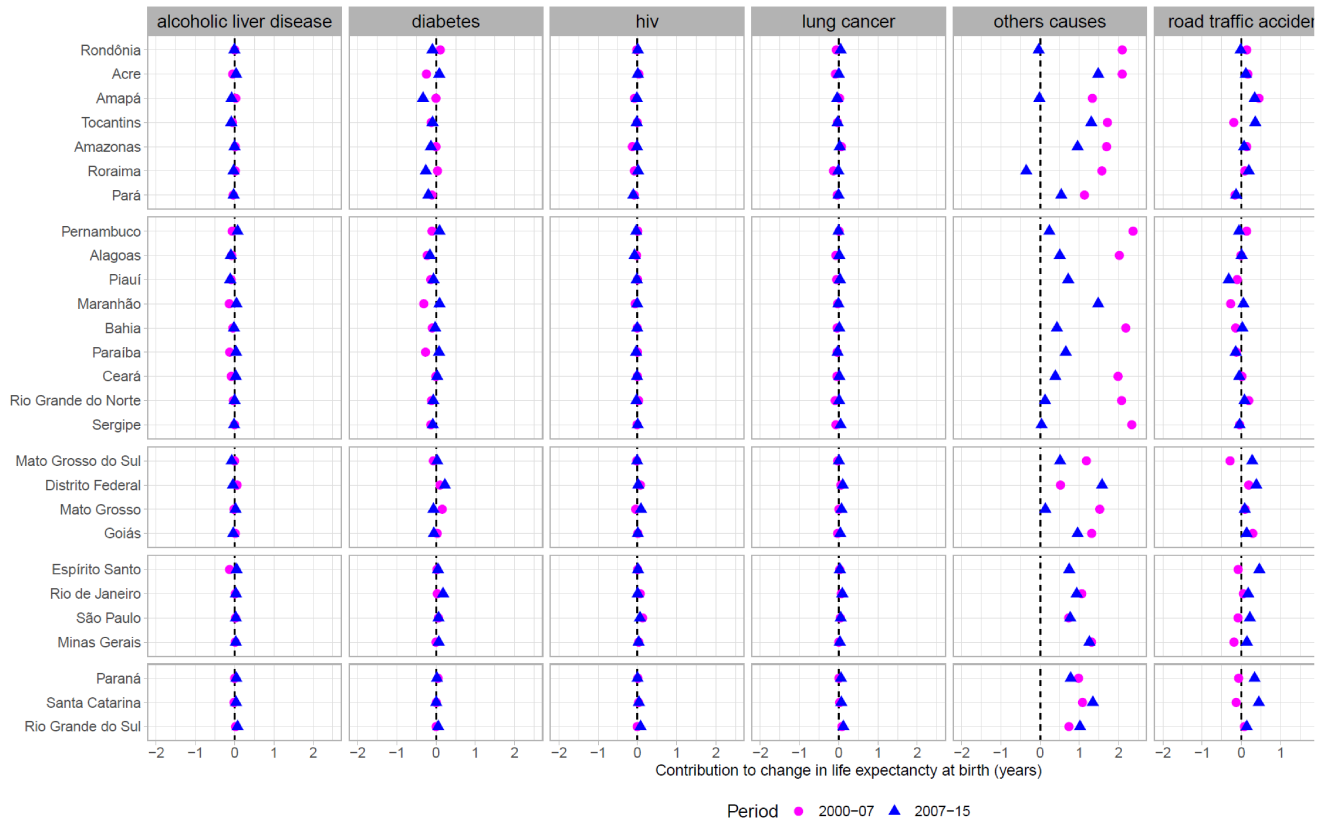
Figure S3. Cause specific contributions to changes in female life expectancy by

Figure S4. Homicide contributions to changes in male life expectancy by state i

Contribution of homicides to changes in male life expectancy in 2007-15

- [−1.5,−1)
- [−1,−0.5)
- [−0.5,0)
- [0,0.75]

Figure S5 Homicide contributions to changes in life expectancy taking different
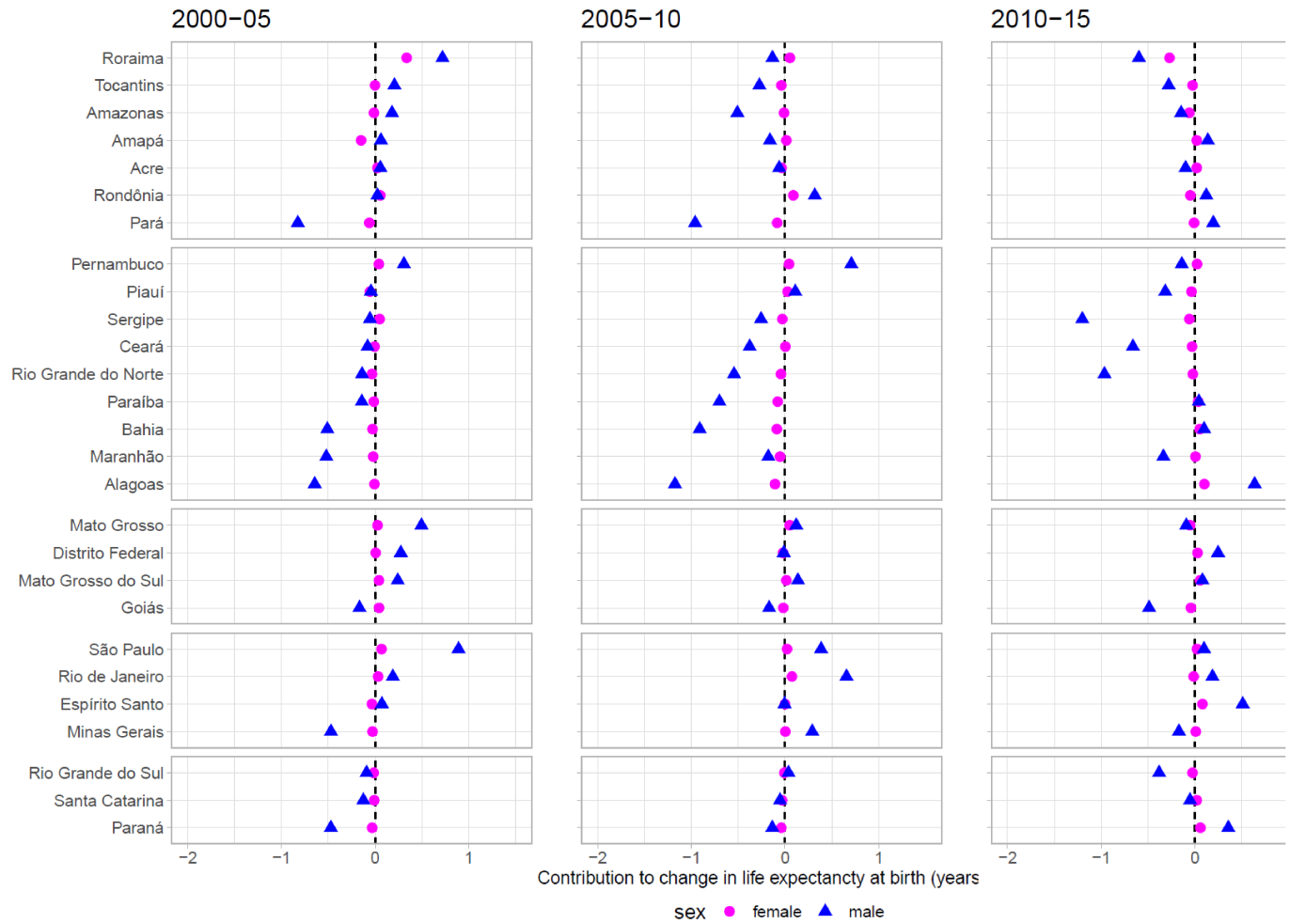
Figure S6. Effect of homicides to life expectancy between 2004-15