Three Studies on Life Expectancy and Lifespan Inequality

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Jayani Wijesinghe

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Abstract

While life expectancy is a key indicator in public health and demography, it may obscure unequal experiences of different population groups. By contrast, lifespan inequality captures variations in age at death, offering a broader view of health disparities. Focusing on lifespan inequality enables policymakers and researchers to identify vulnerable populations, design more equitable health and social policies, and evaluate progress toward reducing inequities.

This thesis is comprised of three interrelated studies that examine life expectancy and lifespan inequality from different perspectives. The first study explores state-level variations in life expectancy and lifespan inequality in the US over a 55-year period, employing Theil's entropy index to measure lifespan inequality and a Panel-Corrected Standard Errors (PCSE) model to assess associated socioeconomic and demographic factors. The analysis reveals a significant negative correlation between life expectancy and lifespan inequality across states. Educational attainment, health insurance coverage, and physician density show negative associations with lifespan inequality, whereas violent crime rates, smoking prevalence, and income inequality exhibit positive associations.

The second study investigates the impact of homicide on life expectancy and lifespan inequality at the state level in the US from 1968 to 2020, focusing on demographic, socioeconomic, and policy determinants. Utilizing data from the US Mortality Database and cause-eliminated life tables and Panel-Corrected Standard Errors (PCSE) models, the study reveals that Southern states experience the most substantial impacts on both life expectancy and lifespan inequality, while the Northeast exhibits comparatively lower effects. Males consistently face greater impacts than females. Key findings underscore systemic inequities: a higher percentage of Black populations and individuals aged 25–34 correlate with greater homicide-related reductions in life expectancy and increased lifespan inequality. Educational attainment, particularly the high school graduation rate, helps mitigate these effects. Corrections and judicial expenditures affect both life expectancy and lifespan inequality. In contrast, police and health spending are associated with decreases in lifespan inequality but no change in life expectancy, whereas welfare expenditures correlate with increased lifespan inequality but are correlated with life expectancy only for the total population.

The final study conducts a comparative analysis of the demographic impacts of three major pandemics: the 1918 influenza pandemic, the HIV/AIDS epidemic, and the COVID-19 pandemic on global life expectancy and lifespan inequality. The study finds that the 1918 influenza pandemic caused the most pronounced reductions in life expectancy, especially among young adults, thereby leading to substantial lifespan inequality. By contrast, HIV/AIDS had a gradual yet enduring impact, predominantly affecting young and middle-aged adults and exacerbating health disparities in regions with limited healthcare resources. The COVID-19 pandemic primarily affected older populations, producing smaller reductions in life expectancy but uniquely decreasing lifespan inequality due to the concentration of mortality among the elderly. Gender-specific effects varied: while the 1918 influenza and COVID-19 pandemics showed relatively uniform gender impacts, HIV/AIDS disproportionately affected women.

Collectively, the findings across these studies underscore the need to address the interconnected issues of life expectancy, lifespan inequality, and systemic disparities. Targeted gender-specific policies and public expenditures (e.g., increased judicial and healthcare funding) have the potential to reshape mortality patterns and mitigate disparities. Pandemic responses should be tailored to protect vulnerable age and demographic groups by ensuring equitable access to healthcare and vaccines.

Notes on Publications

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Chapter 1: Introduction

1.1 Overview

Life expectancy at birth has long been a central metric for comparing mortality across populations, frequently utilized by demographers, actuaries, and other researchers. The widespread use of life expectancy arises from its valuable characteristics. Unlike crude death rates, it adjusts for differences in age structures and provides a concise summary measure of mortality, expressed in easily understood terms (i.e., years). Despite its usefulness in representing the average level of mortality, life expectancy has certain limitations. One significant limitation is its focus on average outcomes, which overlooks the variation in mortality within a population. This can be problematic because life expectancy assumes an average lifespan for a given cohort but does not account for the spread of mortality ages (van Raalte et al., 2018). For instance, two populations may share the same life expectancy yet exhibit distinct patterns in the age distribution of deaths. Mortality in one population might be more dispersed, with a higher proportion of deaths at younger ages, while in the other, deaths might be more concentrated at older ages, reflecting compressed mortality (Kannisto, 2000). Therefore, scholars and policymakers are increasingly focusing on lifespan inequality: a measure that captures the *dispersion* of the age-at-death distribution (Smits & Monden, 2009; Van Raalte et al., 2018). While life expectancy summarizes the *average* lifespan, lifespan inequality highlights how *spread out* or *concentrated* deaths are across different ages, offering deeper insight into population health dynamics (Van Raalte et al., 2012)

Considering the importance of lifespan inequality, it is vital to distinguish between its implications at both the individual (micro) and the population (macro) levels. At the individual level, large disparities in age-at-death—across socio-economic or other demographic groups—reflect the inconsistency in the risk of death. This, in turn, can lead to greater uncertainty for less advantaged individuals when planning their lives, while more advantaged groups face fewer uncertainties. At the population level, high lifespan variation can signal heterogeneity in overall population health, underscoring the need for targeted policy interventions (Van Raalte et al., 2018)

At the individual level, this generates deep consequences when individuals make decisions about lifecycle investment and consumption, including those related to education, training, and retirement (Edwards, 2013). For example, considering the investment in education, as Preston et al. (1972) suggest, a society with a longer life expectancy, where death occurs more frequently at older ages, is more likely to invest in long-term human capital development, because the returns on these investments are more predictable. Lee and Goldstein (2003) elaborate on this idea, noting that "From the point of view of a rational life cycle planner, an extended period of quasi-adulthood probably makes sense for those who can expect to live a long time. A long investment horizon makes it worthwhile to invest more in one's human capital and stay in school longer. Likewise, it makes experimentation less costly and potentially more rewarding" (p. 193). In essence, when life expectancy increases and lifespan inequality decreases, individuals have more time to invest in their education and skills. As the time horizon for returns on education investment grows, it becomes more rational for individuals and society to prioritize education.

This shift in education investment strategies has delayed other life milestones such as marriage and childbearing (Lee and Goldstein, 2003). Interestingly, the pace of change in these life course events, such as the mean age at first marriage and first birth, has accelerated even more rapidly than changes in life expectancy itself, suggesting that the broader societal shifts brought about by increased longevity and decreased lifespan inequality are driving these delays (Lee and Goldstein, 2003). Further, generally, low lifespan inequality alongside increases in average longevity could affect reproductive behavior. For example, according to Zureick (2010), low lifespan inequality provides an opportunity for the parents to build a more desired family by planning to have one or two additional children (insurance effect), and later another child is required only after obtaining the desired size of the family if another child dies (replacement effect).

In addition, an increase in lifespan inequality leads to variability in other social spheres, including participation in work and family life (Brown et al, 2012). For example, Edwards and Tuljapurkar (2005) proposed that the impact of higher lifespan inequality on participation in work, particularly age at retirement, is unclear. Individuals can decide to retire earlier, viewing retirement as a reward for years of work when there is a greater lifespan inequality. In contrast, individuals would be motivated to work longer to increase their savings due to the greater uncertainty of transition to ill health. Therefore, it is hard to determine how lifespan inequality will affect the individual's decisions related to saving and retirement, as it is also unclear whether bequests are made intentionally or as a result of unplanned circumstances (Edwards, 2013).

At the macro level, understanding the heterogeneity of population health and lifespan is critical for projections in insurance and annuity markets, and for planning public medical care and pension schemes (van Raalte et al, 2018). For example, additional costs arise in the insurance and annuities markets when there is greater variability of age at death. Insurance companies charge excess premiums under higher uncertainty and lifespan inequality to avoid financial loss in case only individuals who expect to live longer purchase their policies (Edwards and Tuljapurkar, 2005). Furthermore, at the individual level, lifespan inequality is costly even when the individual has an actuarially fair annuity. While income from an annuity may cover consumption costs, it does not account for utility risks associated with lifespan inequality (Edwards, 2013). Moreover, considering the cost of lifespan inequality on the public pension system, the cost of helping those who live longer is not balanced by earlier deaths. This is because the revenue is collected by the dependents of individuals who die earlier. Furthermore, individuals who die earlier have contributed less to the system and individuals who live longer benefit more, increasing inequality in the pension system because poor individuals have a survival disadvantage (Edwards and Tuljapurkar, 2005).

Beyond the economic implications, lifespan inequality has psychological implications. For instance, Wilmoth and Horiuchi (1999) proposed that changes in lifespan inequality have the potential to change public attitudes about death. In situations with low lifespan inequality, fear of death may decrease because death follows a more predictable, 'natural' order. Deaths that occur outside of this order such as the premature death of younger individuals can generate more fear. For example, American mothers experienced great anxiety about their responsibility to ensure their children's survival and protect them from early death until the development of medicine and public health at the beginning of the 20th century (Dye and Smith, 1986)

Considering the correlation between life expectancy and lifespan inequality particularly in the global perspective, Smits and Monden (2009) indicated that countries with similar life expectancies may have different lifespan inequalities. This illustrates that a particular average life expectancy can result from either narrow or broadly dispersed age distributions at death (Aburto et al., 2020). Moreover, the dynamics of life expectancy and lifespan inequality can be changed by shifts in mortality patterns. Van Raalte and Caswell (2013) and Zhang and Vaupel (2009) argue that life expectancy can rise as mortality decreases across all age groups. Conversely, lifespan inequality diminishes as mortality rates fall below a certain population-specified age threshold. Additionally, the pattern of life expectancy and lifespan inequality can also differ among demographic groups. For instance, according to van Raalte et al. (2018), life expectancy increased among Finnish females across all income, education, and occupational categories between 1971 and 2017. In contrast, lifespan inequality diminished for Swedish females who survived to younger ages from 1990 to 2010, whereas it grew for those who survived to older ages (Engelman et al., 2014). Conversely, while lifespan inequality diminished among the more privileged group within society over time, the more disadvantaged group experienced significant lifespan inequality. Specifically, lifespan inequality decreased only among nonmanual workers, with manual workers experiencing stagnation (van Raalte et al., 2012).

Considering geographical disparities in lifespan inequality, we can identify important studies such as Edwards and Tuljapurkar, (2005); Peltzman, (2009); Smits and Monden, (2009); Tuljapurkar, (2010); Gillespie et al., (2014); Neumayer and Plumper, (2016); Aburto and van Raalte, (2018); and Permanyer and Scholl (2019), which have focused on the cross-country comparisons. Those studies indicate that cross-country inequalities contributed 10 to 30 per cent of inter-individual lifespan inequality (Pradhan et al., 2003; Smits & Monden, 2009; Edwards, 2011; Clark & Snawder, 2020). Furthermore, these studies identified some important socioeconomic and demographic factors associated with cross-country lifespan inequality. For example, Shkolnikov et al., (2011) and Neumayer and Plumper (2016) have identified the relationship between income inequality and lifespan inequality, and income redistribution and lifespan inequality, respectively. Moreover, Clark and Snawder (2020) identified that economic growth, maternal mortality, rates of fertility, the prevalence of HIV, and accessibility to improved water sources also cause lifespan inequality. Low-educated whites experienced declines in adult life expectancy and increased lifespan inequality, while college-educated whites saw rising life expectancy and reduced lifespan inequality from 1990 to 2010 in the USA (Sasson, 2016). These findings underscore the importance of considering heterogeneity and uncertainty in understanding lifespan inequality.

1.1.1 Measuring Lifespan Inequality

Researchers such as Kannisto (2000), Shkolnikov et al. (2003), Vaupel et al. (2011), Wilmoth and Horiuchi (1999), and van Raalte and Caswell (2013) have compared different lifespan inequality indices, noting high correlations among them. For example, van Raalte et al. (2011) found that $e^{\dagger}$ (or 'e-dagger'), the Gini coefficient, Theil's index, mean logarithmic deviation, standard deviation, and interquartile range are highly correlated. Wilmoth and Horiuchi (1999) and Vaupel et al. (2011) also observed strong correlations between the Gini coefficient, Keyfitz's entropy, and the coefficient of variation.

Despite these correlations, indicators have some unique properties. Some, like the variance and standard deviation, measure absolute inequality, while others, like the Theil index or Gini coefficient, capture relative inequality (van Raalte and Caswell, 2013; Wrycza et al., 2015). Another important feature is additive decomposability, which allows total inequality to be split into between-group and within-group components (van Raalte et al., 2011). Indicators like variance, the Theil index, and mean logarithmic deviation have this property, making them easier to interpret. $E^\dagger$ is also popular due to its clear public health meaning and its decomposability (Shkolnikov et al., 2011; Zhang and Vaupel, 2009). Although the Gini coefficient is not generally decomposable, it's valued for its intuitive interpretation and connection to the Lorenz curve (Allison, 1978; van Raalte and Caswell, 2013). It also captures changes in the middle of the lifespan distribution, where many preventable deaths occur.

Lifespan inequality measures can also be assessed against three desirable properties from income inequality indices (Shkolnikov et al., 2003, p. 313): (1) population-size independence, (2) mean independence, and (3) the Pigou-Dalton condition. The IQR meets the first two but not the third; variance and standard deviation meet the first and third but not the second. The Gini coefficient and Theil index satisfy all three, though the Theil index is more complex to interpret (Allison, 1978). Despite its complexity, this study adopts the Theil index as it offers both nuanced analytical capability and practical advantages for examining lifespan inequality across varied social and health-related contexts.

1.2 Research Articles and Significance of Research

This thesis is comprised of three research papers, each addressing a distinct but interconnected research question aimed at advancing our understanding of life expectancy and lifespan inequality and their determinants. The first paper, titled *State-Level Differences in Life Expectancy and Lifespan Inequality: Is It a Matter of Socioeconomic Inequalities?* explores two key research questions: (1) What are the state-level differences in life expectancy at birth and lifespan inequality in the U.S.? and (2) What is the association between socioeconomic, demographic, and health factors and state-level lifespan inequality? The second paper, *Homicides and Their Impact on Life Expectancy and Lifespan Inequality at the State Level in the USA, 1968–2020*, addresses two important research questions: (1) What is the impact of homicide on life expectancy and lifespan inequality at the state level in the U.S.? and (2) What are the socioeconomic and demographic determinants of the effect of homicide on changes in life expectancy and lifespan inequality? The third paper, *A Tale of Three Pandemics: Impacts on Life Expectancy and Lifespan Inequality*, compares the effects of the 1918 influenza pandemic, the HIV/AIDS epidemic, and the COVID-19 pandemic on life expectancy and lifespan inequality, offering insights into how public health crises shape long-term inequalities.

To date, little is known about geographical disparities in lifespan inequality within countries and how socioeconomic and demographic inequalities contribute to lifespan inequality. Therefore, the first paper of this thesis is focused on two research questions related to the geographical disparities of lifespan inequality in the US context. Considering the US, health spending per capita is up to four times higher than in other countries such as Japan, Switzerland, UK, Sweden, Australia and France (Roser, 2020). Despite this, the US has a relatively lower life expectancy. For example, in 1880, the average life expectancy of Americans was approximately 39 years. Over the 20th century, this figure more than doubled, peaking at around 78.9 years in 2014. However, since then, life expectancy in the U.S. has declined, dropping to approximately 76.4 years by 2021 (Roser, 2020). This decline will continue due to the COVID-19 pandemic (Marois et al, 2020). At the state level, Mississippi, with a life expectancy of 71.9 years is five years lower than the national average, and eight years lower than Hawaii, with the highest life expectancy. Louisiana at 73.1 and West Virginia at 72.8 are the two states with the next lowest life expectancy in 2020 (Arias et al., 2022). Looking at the life expectancy data across the US gives a different picture from looking at the country as a whole. It is clear that even though the US has high per capita health expenditure, significant inequalities can be seen at the state level. Therefore, it is important to understand the health inequalities of states because legislation, policies, and programs that provide health care, economic assistance and social services are administered and implemented at both national and state levels.

One contributing factor to early mortality is homicide. Grinshteyn and Hemenway (2019) identified that the overall homicide rate in the US is seven times higher than in other high-income countries. Males in the US are approximately nine times more likely to be victimized for homicide than their male counterparts in other high-income countries and the corresponding ratio is four times more for females. Additionally, even though nonwhites have a greater risk of homicide victimization than whites, the white homicide rate was four times higher than the average rate in other high-income countries in 2015 (Grinshteyn and Hemenway, 2019). Homicide was the third leading cause of death among 15–34-year-olds in 2016 (National Center for Injury Prevention and Control, 2016). Homicide victims are young, which contributes to the lower life expectancy in the US in comparison with other rich countries. Considering geographical disparities, homicide rates are high in the South region, particularly in Louisiana (19.8 per 100,000), Mississippi (20.7 per 100,000), and Alabama (14.9 per 100,000), where the rates are more than double the national average of 6.3 per 100,000 individuals, reflecting substantial regional disparities (National Center for Health Statistics, 2023). Despite these differences, and the obvious contribution of homicide to lower life expectancy (Lemaire, 2005; Redelings et al, 2010; Sharkey & Friedson, 2019; Kim, 2019), little is known about the contribution of homicide to lifespan inequality and its determinants. Therefore, the second paper of this thesis focuses on this issue.

The third paper broadens the scope of the thesis to consider the global context by comparing the impacts of three different pandemics on life expectancy and lifespan inequality. The recent COVID-19 pandemic has brought renewed attention to the role of health crises in shaping life expectancy and lifespan inequality. Studies have shown that pandemics can exacerbate existing inequalities, disproportionately affecting vulnerable populations who lack access to adequate healthcare (Marois et al., 2020). However, most studies on health crises have been focused on life expectancy (Trias-Llimós and Bilal, 2020; Marois et al., 2020; Aburto et al., 2022; Kuehn, 2022) and there is a lack of study in this area of lifespan inequality and health crisis. Therefore, the third paper investigates the impacts of the 1918 Influenza pandemic, HIV/AIDS, and COVID-19, on life expectancy and lifespan inequality.

Overall, the thesis contributes to the theoretical, contextual and practical aspects in the fields of demographic, health, and social economics through these three linked research papers. Theoretically, the thesis extends the current understanding and validity of the relationship between life expectancy and lifespan inequality using different demographic, health and economic aspects. Moreover, this research incorporates important factors such as geographical disparities, homicide and health crises, which can explain changes in life expectancy and lifespan inequality. Also, the thesis is novel, as it explores the variation in life expectancy and lifespan inequality at a regional and local level, which contributes new knowledge about the regional and local level differences.

Practically, this thesis has significant implications for policymakers. According to Edwards and Tuljapurkar (2005, p.645), "the challenge before health policies in this century is to reduce inequality, not just lengthen life". Therefore, studying lifespan inequality and life expectancy is an essential step towards a broader understanding of health outcomes which helps to evaluate existing programs and policies, improve social, economic and health interventions, and reduce inequalities in health, especially lifespan inequality. The findings of the three papers in this thesis and their policy implications provide a comprehensive picture to policymakers in the economic, social, and health sectors.

This thesis is also important for understanding new trends in life expectancy and lifespan inequality and rethinking and adjusting current policies. The thesis provides unique policy insights that allow countries to develop more effective health, economic, and social programs and policies to address the existing challenges of regional disparities, homicide and pandemics.

It also provides guidance to address the problems and issues related to lifespan inequality that are global and require international policy responses that are aligned with Sustainable Development Goals (SDGs). These goals emphasize the importance of health and well-being as core components of sustainable development. SDG 3, which aims to ensure health and well-being for all at all ages, is particularly significant as it acts as a cornerstone for achieving other SDGs. The 2030 Agenda explicitly highlights the need to "promote physical and mental health and well-being, and to extend life expectancy for all", emphasizing universal health coverage and access to quality healthcare with the principle that "no one must be left behind" (United Nations, 2015, p.7). Progress on health outcomes, including reduced lifespan inequality, directly influences other SDGs and, conversely, benefits from advances in goals such as education, economic growth, and reduced inequalities. Target 16.1 of the SDGs focuses on "significantly reducing all forms of violence and related death rates" (United Nations, 2015, p.25), with its associated indicator measuring the number of homicide victims per 100,000 population by sex and age.

SDG 1 (End poverty in all its forms everywhere) and SDG 10 (Reduce inequality within and among countries) are also deeply interconnected with the themes of this thesis, as poverty and inequality are risk factors for poor health and violent crime at both individual and national levels (Wolf et al, 2014; Paré and Felson, 2014; Pickett and Wilkinson, 2015). These issues perpetuate a vicious cycle, where inequality exacerbates violence and poor health, further hindering economic and social development (Osawe and Onyepuemu, 2015). Lifespan inequality not only intersects with SDG 3 but also impacts SDG 4 (Quality education), as uncertainty in lifespan can discourage investment in education, thereby limiting economic opportunities and hindering sustainable development. Moreover, lifespan inequality is also linked to SDG 8 (Decent work and economic growth), as it imposes direct and indirect costs on society, influences work decisions, and affects forecasts in insurance and annuity markets. Understanding and addressing lifespan inequality is thus a key step toward achieving equitable and sustained economic growth. Furthermore, the United Nations Development Programme includes lifespan inequality, along with income inequality and education inequality, in its Inequality-Adjusted Human Development Index (IHDI) (UNDP, 2011; UNDP, 2013). Therefore, by improving understanding of health inequality, in particular lifespan inequality at the global, regional, and national levels, this thesis can support government and policymakers in their efforts to understand the root causes of inequality.

1.3 Thesis Outline

The remainder of the thesis is organized as follows. Chapter 2 presents the first research article, answering the research questions on how socioeconomic and demographic factors contribute to lifespan inequality at the state level in the US. Chapter 3 presents the second research article, answering the research questions on how homicide contributes to lifespan inequality and lifespan inequality at the state level in the US. Chapter 4 presents the third research article, answering the research questions on how health shocks including the 1918 Influenza, HIV/AIDS, and COVID-19 impacted life expectancy and lifespan inequality. Chapter 5 concludes the thesis by providing a summary of the key findings, discussing their policy implications, and exploring potential directions for future research.

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Chapter 2: State-Level Differences in Life Expectancy and Lifespan Inequality: Is It a Matter of Socioeconomic Inequalities?

Abstract

Lifespan inequality refers to the variation in the age at which people die or the uncertainty surrounding the time of their death. This study investigates the patterns of lifespan inequality at the state level in the US over 55 years, utilising Theil's entropy index. We also explore the demographic and socioeconomic factors associated with lifespan inequality using a Panel-Corrected Standard Errors (PCSE) model. We observe a strong and statistically significant negative correlation between life expectancy and inequality in lifespan at the state level overall and for both males and females. In terms of demographic and socioeconomic factors, the percentage of individuals who have completed high school and college education, the percentage of the Hispanic population, the number of physicians, the percentage of individuals under 65 with insurance, and population growth are all negatively associated with lifespan inequality. Moreover, there is a positive association between lifespan inequality and the rates of violent crime, CO_2 emissions per capita, cigarette smoking, and income inequality. Our results reiterate that policies aimed at tackling disparities in socioeconomic position could also serve as useful strategies for addressing health disparities.

Keywords

Lifespan inequality
Theil index
Socioeconomic inequality
United States

2.1 Introduction

Life expectancy at birth, long regarded as a cornerstone indicator in public health, demography, and epidemiology, serves as a key metric for assessing the overall health and well-being of populations. Despite its wide application, life expectancy bears inherent limitations. First and foremost, it neglects the present health status of individuals, offering a mere average that overlooks the diverse health experiences within a population. Furthermore, it does not consider the distribution of life expectancy within a population and thus fails to capture the dynamic variations inherent in a population's longevity. In response to these shortcomings, scholars and policymakers are increasingly turning their attention to the concept of lifespan inequality (Smits & Monden, 2009; Van Raalte et al., 2018), which goes beyond the conventional emphasis on life expectancy. Lifespan inequality illustrates variations in age at death and the uncertainties surrounding the timing of mortality, painting a more comprehensive picture of a population's health profile.

According to Van Raalte et al. (2018), lifespan inequality has significant implications at the individual and population levels. On an individual level, it offers insights into the diverse health trajectories of individuals, influencing decisions related to education, career choices and retirement planning (Edwards & Tuljapurkar, 2005; van Raalte et al., 2018). At the population level, it shapes mortality projections, influences the dynamics of insurance and annuity markets, and contributes to disparities within public pension systems. For instance, individuals with a longer lifespan are more inclined to acquire insurance policies to mitigate potential financial losses. On the other hand, insurance companies adjust premiums based on uncertainty and variation in lifespan. When examining public pension systems, it is important to note that individuals who die at a younger age have made smaller contributions to the system. In contrast, individuals who live longer will overall receive greater benefits from the public pension system. This creates socioeconomic inequalities that are worsened by the fact that poor individuals are at a disadvantage when it comes to survival (Edwards & Tuljapurkar, 2005).

Few studies have undertaken a comprehensive examination of lifespan inequality within a specific country, with such studies limited to Shkolnikov et al. (2003) in Russia, van Raalte et al. (2011) in ten European countries, van Raalte et al. (2014) in Finland, Sasson (2016b) in the US, Brønnum-Hansen (2017) in Denmark, Permanyer et al. (2018) in Spain, and Seaman et al., (2019) in Scotland. These studies have contributed valuable insights to our understanding of lifespan inequality. In particular, van Raalte et al. (2011) discovered that individuals with the lowest level of education saw a higher degree of lifespan inequality compared to those with the highest level of education. Furthermore, van Raalte et al., (2014) found that manual occupational groups had a higher degree of lifespan inequality compared to non-manual occupational groups in Finland. However, while life expectancy in Denmark has been rising, the most disadvantaged groups have seen little to no improvement in lifespan inequality, while the least disadvantaged groups have shown a decrease in lifespan inequality (Brønnum-Hansen, 2017).

Turning to the US, despite investing up to four times as much as other OECD nations in health (OECDSTAT, 2017), the US had a life expectancy ranking of 34th globally in 2016, placing it below most other high-income countries and many middle-income countries (WHO ,2018). It has therefore often been identified as an outlier among high-income nations with similar overall life expectancies and exhibits remarkable variations in both life expectancy and lifespan inequality (Aburto et al., 2020; Crimmins et al., 2010; van Raalte et al., 2018; Rogers et al., 2021; Vaupel et al.,2011). Furthermore, life expectancy in the US exhibits significant variation based on geographical location and socioeconomic status. Chetty et al. (2016), Meara et al. (2008), Case and Deaton (2015), (2017), and Brown et al. (2012) have each observed that the least educated populations in the US have lower life expectancy. Sasson (2016b) also examined the US from 1990 to 2010 and found that among low-educated whites, adult life expectancy has declined for both males and females. Meanwhile, lifespan inequality has increased for high school-educated whites, significantly contributing to overall lifespan inequality. In contrast, college-educated whites have experienced rising life expectancy and a decrease in the variability of age at death. For blacks, adult life expectancy has generally increased, with lifespan inequality levelling off or decreasing across most educational groups.

On the other hand, a comparison of mortality rates between the US and peer countries such as Australia, Canada, Norway, the UK, and Finland, reveals a persistent trend of higher mortality rates in the US, and this disparity has significantly intensified since the year 2000 (Harris et al., 2021**).** Furthermore, since the 1970s the US has consistently exhibited higher probabilities of death across age groups from 15 to 65 years when compared to its peer countries (Harris et al., 2021). Moreover, the ratio of mortality rates at these ages in the US to those observed in the peer countries experienced significant growth between 2000 and 2010, and again from 2010 to 2016. Post 2000, there was a notable surge in the relative risk of death among late adolescents and young adults (below the age of 40) in the US, surpassing the increase observed in any other age cohort. However, there was a more consistent and gradual rise in the relative mortality risk observed among older age cohorts from the 1970s through 2016 (Harris et al., 2021).

To have a comprehensive understanding of the various dimensions of life expectancy and lifespan inequality in the US, it is imperative to navigate the intricate sociodemographic

diversity of the country at the subnational level. The role of Federalism is an integral component of the U.S. government system, granting significant autonomy to each State in formulating and implementing policies and procedures leading to distinct social and economic challenges, healthcare infrastructures, and cultural disparities that are the key determinates of lifespan inequality (Edwards and Tuljapurkar 2005; Brown et al.2012; Sasson 2016a). Therefore, tracking lifespan inequality at the state level over time permits a deeper understanding of lifespan inequality and its fundamental causes and acts as a tool for assessing progress toward the goal of more equitable health outcomes, as enshrined in the Healthy People 2030 objective: "Eliminate health disparities, achieve health equity, and attain health literacy to improve the health and well-being of all" (Office of Disease Prevention and Health Promotion, n.d.). . Furthermore, monitoring subnational trends in life expectancy and lifespan inequality can shed light on future mortality for both privileged and disadvantaged groups. However, to the best of our knowledge, ours is the first study that examines the long-term trends in lifespan inequality and assesses the association between lifespan inequality and various demographic and socioeconomic variables at the state level. Only a few cross-sectional studies, the majority of which used older data sets, have examined socio-economic and demographic dimensions of lifespan inequality, including Aburto and van Raalte (2018) in Central and Eastern Europe, Edwards and Tuljapurkar (2005) in industrialized countries, Gillespie et al. (2014) in Sweden, Japan, Canada, and the US, Neumayer and Plumper (2016) in western developed countries, Permanyer and Scholl (2019) and Smits and Monden (2009) in the global context, and Tuljapurkar (2010) in Sweden.
In this paper, we address the following research questions:

1. What are the state-level differences in life expectancy at birth and lifespan inequality in the U.S.?
2. What is the association between socioeconomic, demographic, and health factors and state-level lifespan inequality?

The rest of the paper is organized as follows. Section 2 describes the data and provides a brief explanation of the methodology. Section 3 presents the results and analysis of the econometric model. The final section concludes.

2.2 Data and Methods

Our primary source of data for the measurement of lifespan inequality is the US Mortality Database (USMDB),[1] which provides complete life tables by sex for all 50 states and the District of Columbia for each year from 1959 to 2018, with age-specific mortality values up to the age of 110. However, after initial analysis, the District of Columbia was identified as an outlier since its mortality pattern, and socioeconomic, demographic, and health characteristics differ significantly from those of other states. The District of Columbia is therefore excluded from our study.

For the analysis of the determinants of lifespan inequality, the data for the independent variables come from various sources. First, we included key socioeconomic predictors of health (Bayati et al., 2013). Income data were obtained from the Federal Reserve Bank of St. Louis FRED database, and the state-level Gini coefficient from the U.S. State-Level Income Inequality database. We use the percentage of the population who are high school graduates and the percentage of the population who are college graduates from the database developed by Frank (2009) as a measure of population-level educational attainment. Data on the percentage of employees in manufacturing by state was obtained from the Bureau of Labor Statistics(n.d). As measures of health resources, we include the number of physicians per 10,000 population, and personal health care expenditures (calculated as a percentage of state Gross Domestic Product). These data were obtained from the US Census Bureau (U.S. Census Bureau, n.d.). Data on cigarette pack sales per capita were obtained from the Centers for Disease Control and Prevention.

Descriptive statistics for the independent variables are given in Table 2.1. This panel data consists of annual observations for 50 states over the period 1987-2014.

[1] https://usa.mortality.org/

Table 2.1: Descriptive Statistics for the sample

	N	Mean	Std. Dev.	Median	Min	Max
Theil index	1400	3.08	0.45	3.06	2.17	4.41
% of high school graduates	1400	0.61	0.05	0.62	0.45	0.74
% of college graduate	1400	0.17	0.05	0.16	0.07	0.46
Gini index	1400	0.58	0.04	0.58	0.49	0.71
Violent crime rate (per 10,000 population)	1400	44.5	22.38	41.6	5.68	124.43
Cigarette consumption (Pack Sales Per Capita)	1400	81.65	31.62	81.70	15.40	195.10
Total personal health care (% GDP)	1400	13.00	2.82	12.70	4.40	22.30
Physicians (per 10,000 population)	1400	23.89	6.04	23.00	12.20	47.40
% Insurance prevalence under 65	1400	84.44	4.51	85.00	70.60	96.20
Population growth	1400	0.96	0.94	0.80	-5.99	6.24
% Black population	1400	10.21	9.44	7.32	0.25	37.51
% Hispanic population	1400	7.95	9.06	4.77	0.00	47.67
Co_2 per Capita	1400	23.31	19.24	18.22	0.05	139.54
Population density	1400	69.90	95.02	34.75	0.36	465.54
Unemployment rate (%)	1400	5.69	1.87	5.40	2.30	13.70
% Employees in manufacturing	1400	8.95	4.37	8.82	0.04	19.83
Log real per capita income	1400	4.55	0.09	4.55	4.29	4.81

Source: Authors' calculations

Lifespan inequality measures

Kannisto (2000), Shkolnikov et al. (2003), Vaupel et al. (2011), Wilmoth and Horiuchi (1999), and van Raalte and Caswell (2013) have all analyzed features of the indicators of lifespan inequality and revealed strong correlations between various measures. We employ the Theil Index in our analysis as the measure of lifespan inequality, because it is more sensitive than other measures to differences across the full range of the age-at-death distribution, whereas alternatives such as the Gini Index attach lesser weight to high values, which are important in the context of measuring lifespan. We quantify lifespan inequality for the entire population, male and female populations (or other subsets such as regions).

The Theil index for lifespan inequality, which is denoted as T_a, can be calculated as follows:

$$\boldsymbol{T_a = \frac{1}{l_a} \sum_{x=a}^{\omega} d_x \left(\frac{\alpha_x}{\mu_a}\right) log \left(\frac{\alpha_x}{\mu_a}\right)} \quad (1)$$

where a and ω are the youngest and oldest age intervals taken from a given life table, l_a is the radix of the population,[22], μ_a is the average age at death of the population, and d_x and α_x are

[2] Of the starting number of newborns in the life table, usually set at 100,000

the life table number of deaths and the average age at death in the age interval x to $x + 5$, respectively.

Panel Corrected Standard Errors (PCSE) model

The basic econometric specification of the panel regression model is as follows.

$$\boldsymbol{Y_{it}} = \boldsymbol{\beta_0} + \boldsymbol{\beta_k X_{kit}} + \boldsymbol{U_{it}} \tag{2}$$

where Y_{it} is lifespan inequality for state i in period t, X_{kit} is a vector of k independent variables β_{kit} are the corresponding coefficients, and U_{it} is the error term and is assumed to be i.i.d. We estimated separate models for total lifespan inequality, male lifespan inequality, and female lifespan inequality as dependent variables.

First, pooled OLS regression was employed, and the decision between random effect and fixed effect models was determined based on the results of the Hausman Test. Based on this test, we identified the fixed effects model for all models of lifespan inequality as being the appropriate specification (total p<0.001; male p<0.001; and female p<0.001). Therefore, we next estimated fixed effects regressions and checked for the heteroscedasticity and auto-correlation using the Wald test and serial correlation test respectively. These tests revealed evidence of autocorrelation and heteroscedasticity in the panel data (see Appendix 1, Table A1). Next, we checked for cross-sectional dependence among the sample states by employing Pesaran et al.'s (2004) cross-sectional dependence (CD) and scaled Lagrange Multiplier (LM) tests, as well as the Breusch-Pagan LM test (Breusch and Pagan, 1980). The results of these tests clearly reject the null hypothesis of no cross-sectional dependence (see Appendix 1, Table A2).

The stationarity of target variables was checked before model estimation. First-generation unit root tests may yield biased outcomes in the presence of heterogeneity and cross-sectional dependence (Pesaran, 2007). Thus, following Pesaran (2007), we employed second-generation panel unit root tests: the cross-sectional ADF (CADF) and cross-sectionally augmented IPS (CIPS). The results of CADF showed that total personal health care, percentage of Black population, and percentage of Hispanic population were stationary in first differences, while other variables were stationary in both levels and first differences (see Appendix 1, Table A3).

The CIPS results indicate that the Gini index, total personal health care (as a percentage of GDP), percentage of Black population, percentage of Hispanic population, population density and real per capita income each have a unit root but become stationary when the first difference is taken. In conclusion, based on the CIPS test, we used first differences in our PCSE models for the Gini index, total personal health care (as a percentage of GDP), percentage of Black population, percentage of the Hispanic population, population density and real per capita income, while the remaining variables are measured in levels.

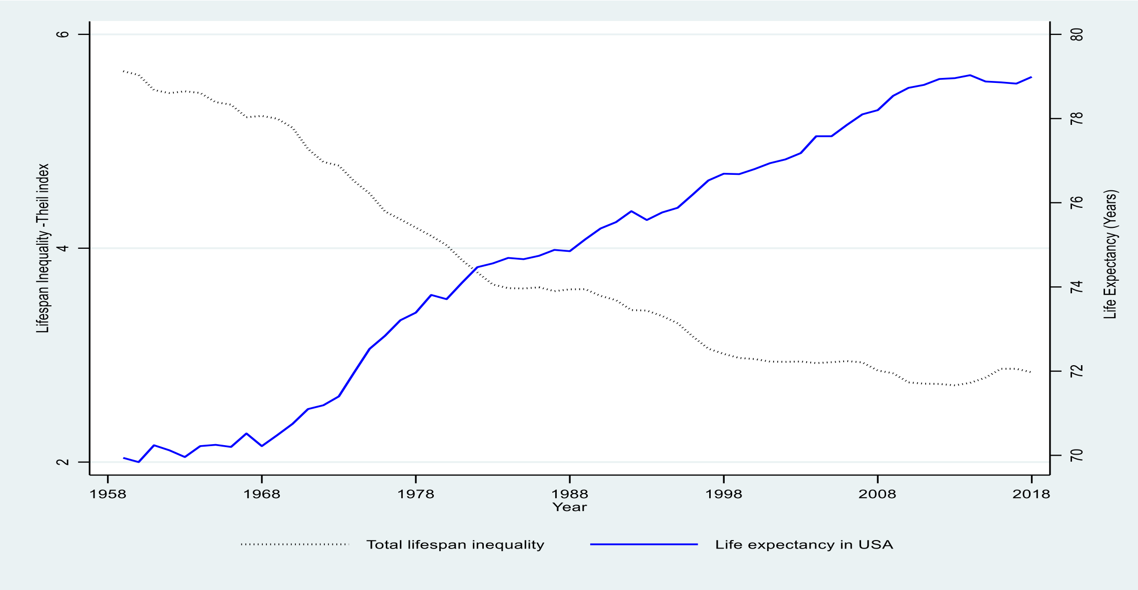
To address the econometric issues present in our data, including heteroscedasticity, serial correlation, and cross-sectional dependence, a suitable approach is to utilize the Feasible Generalized Least Squares (FGLS) method. This method, along with the conventional Error Correction technique, can effectively resolve the concerns, as suggested by Wooldridge (2010). However, Beck and Katz (1995) suggested that researchers employ OLS with heteroscedastic panels of corrected standard errors (OLS-PCSE) for analysing cross-sectional time-series data. This is because the standard errors of the estimated coefficients using FGLS may potentially underestimate the sampling variability. The OLS-PCSE method outperforms the FGLS method in accurately estimating standard errors, as demonstrated in their Monte Carlo analyses. Moreover, the Feasible Generalized Least Squares (FGLS) estimator is most suitable for panels with a larger number of periods (T) compared to the number of cross-sectional units (N). Conversely, panels with a smaller number of periods compared to the number of cross-sectional units are better suited to the Panel Corrected Standard Errors (PCSE) estimator We note that our sample has small T (27) and large N (50). An additional advantage of utilizing the OLS-PCSE approach is that it allows for the simultaneous correction of homoscedastic disturbances across cross-sections (Reed and Webb, 2010). Bailey and Katz (2011)assert that the PCSE estimates are resistant to variations in unit heteroscedasticity and possibly simultaneous correlation among units. Based on these factors, we apply PCSE as the most suitable estimator for analysing the panel data.

2.3 Results and Discussion

Trends in Life Expectancy and Lifespan Disparity

Life expectancy at birth in the US increased by almost 9.05 years between 1959 and 2018, from 69.94 years in 1959 to 78.99 years in 2018, as shown in Figure 2.1. The highest decadal rise in life expectancy occurred between 1970 and 1980, with a 2.96-year increase from 70.75 to 73.71 years. The rise in life expectancy was not, however, continuous or universal. For example, life expectancy decreased in 1993, was stable in 2005, and has been relatively constant in recent years. Life expectancy in the US in 2010 was 78.7 years, the same as in 2018. Until recently, the last time the US saw a sustained drop in life expectancy for selected years was in 1918, during the First World War and the outbreak of Spanish influenza.

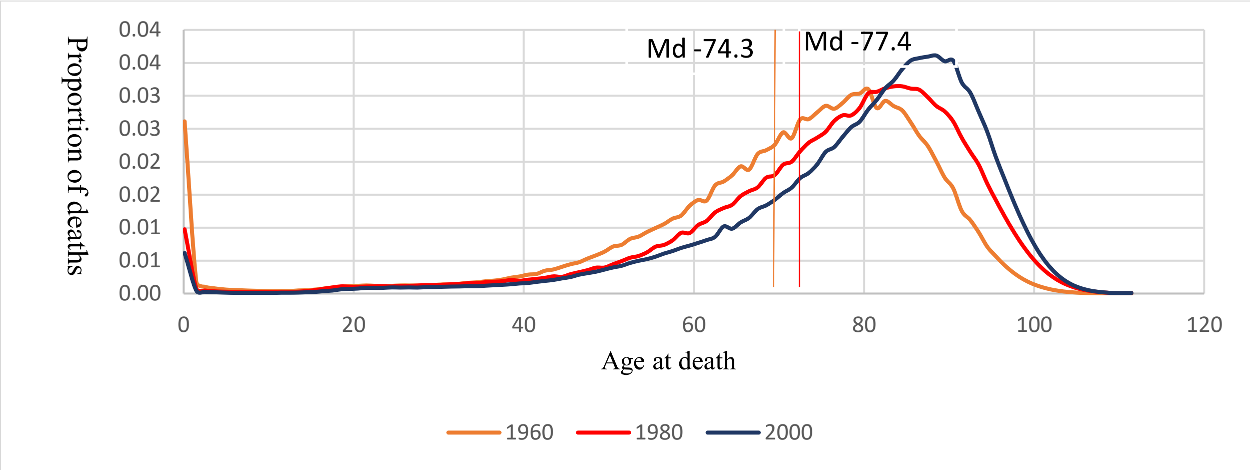
Figure 2.1: Life expectancy and lifespan inequality in the US: 1959-2018



Source: Authors' calculations based on the US Human Mortality Database

Figure 2.1 demonstrates a negative relationship between inequality in lifespan and life expectancy at the national level. Life expectancy has increased over time while lifespan inequality has decreased. This is because increases in life expectancy are frequently the result of decreases in infant mortality and premature death (Shkolnikov et al., 2011). This is further supported by Figure 2.2, which demonstrates that infant mortality has declined dramatically, with the distribution of ages at death steadily shifting to the right and fatalities increasingly concentrating just above the median age at death. On the other hand, according to Case and Deaton (2015) the US is the only developed nation in which midlife mortality has been increasing. A growing number of prime-age people (aged 20 to 49) are dying from 'despair' (Acciai & Firebaugh, 2017; Muennig et al., 2018), with the opioid epidemic, suicide, and alcohol-related mortality being attributed as causes (Muennig et al., 2018). This effect is not noticeable in Figure 2.2, where the data stops in 2000, but it has halted both the increase in life expectancy in recent years, as well as the reduction in lifespan inequality, as shown in Figure 2.1.

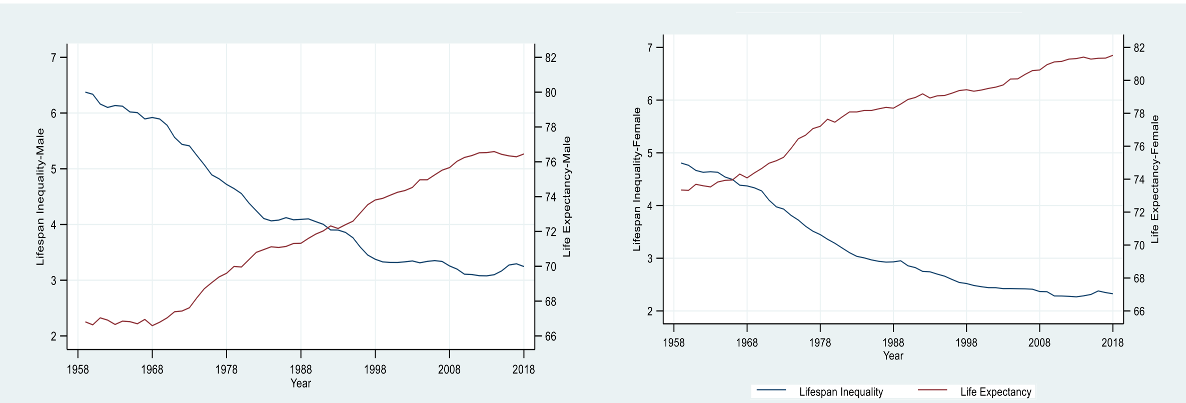
Figure 2.2: Age distribution of deaths in the US, 1960-2000



Source: Authors' calculations based on the US Human Mortality Database

When gender differences in life expectancy and lifespan inequality are examined, females have greater life expectancy; nevertheless, in the US their gains in life expectancy over time have been less than those of males, as shown in Figure 2.3. In 1959, the average life expectancy for a male was 66.81 years, while the average life expectancy for a female was 73.34 years (a difference of 6.53 years). The average male life expectancy increased by 9.64 years to 76.45 years between 1959 and 2018. The life expectancy of women grew by 8.18 years, reaching 81.52 years. The male-female disparity in life expectancy decreased from 6.53 years in 1959 to 5.07 years in 2018. Figure 2.3 also illustrates the relationship between lifespan inequality and life expectancy at birth for men and women. The data suggest a substantial negative correlation between life expectancy and lifespan inequality (male r = -0.97 and female r = -0.99). As life expectancy has increased over time, lifespan inequality has decreased for both sexes (Figure 2.3).

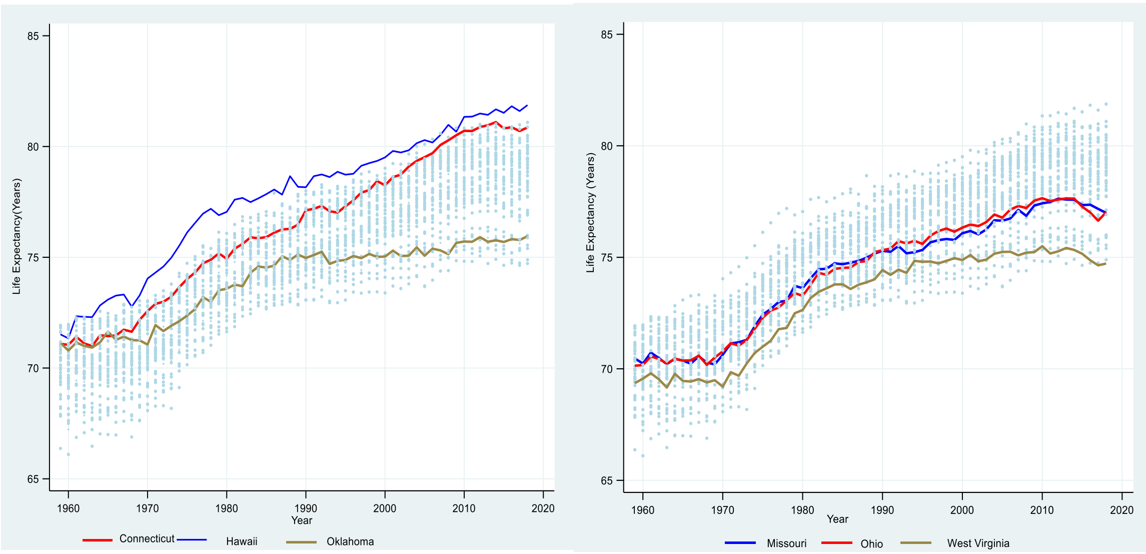
Figure 2.3: Lifespan inequality by gender in the US, 1959-2018



Source: Authors' calculations based on the US Human Mortality Database

As shown in Figure, 2.4, life expectancy grew in all States between 1950 and 2018. However, not all states performed the same. For example, even though life expectancy was similar in Connecticut and Oklahoma in 1959, Connecticut's life expectancy has risen substantially more, and the life expectancy gap between those two states has widened (Figure 2.4, Panel (a)). Moreover, life expectancy has plateaued or even declined in recent years in some states, such as Ohio, Missouri, and West Virginia (Figure 2.4, Panel (b)).

Figure 2.4: Overall trends in Life expectancy by State and highlights - Total Population



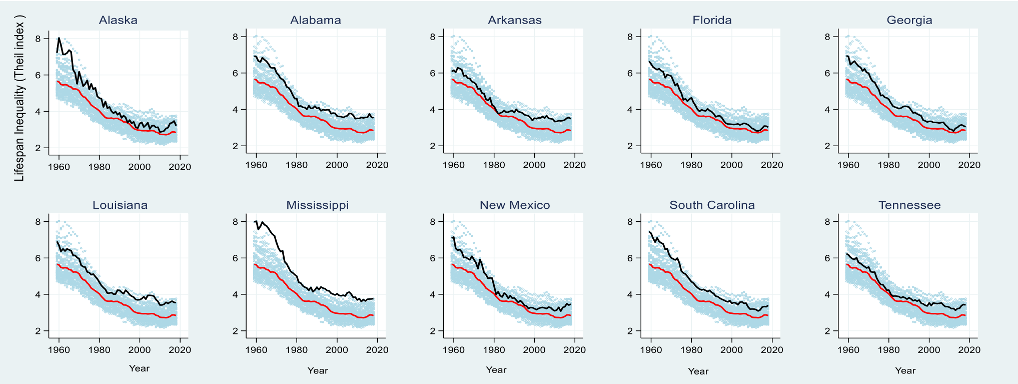
(a) (b)

Source: Authors' calculations based on the US Human Mortality Database

Comparing national-level lifespan inequality with state-level lifespan inequality, different patterns of lifespan disparity can be observed, as shown in Figure 2.5.

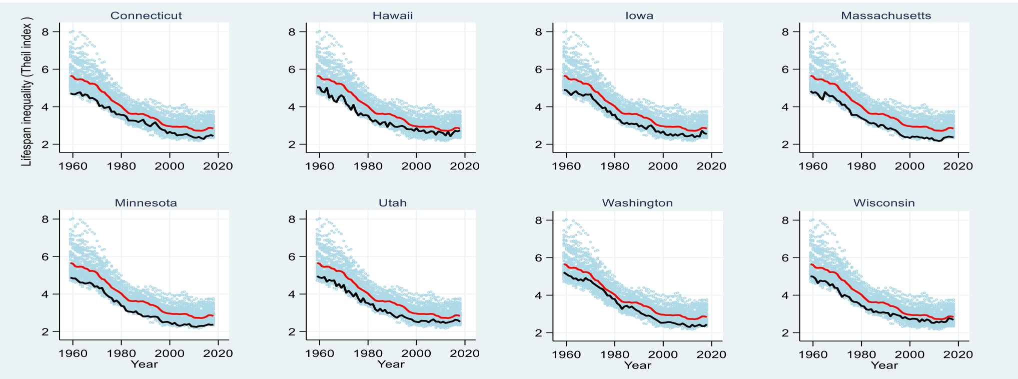
Figure 2.5a highlights states that recorded higher lifespan inequality than the national level over the entire period, while Figure 2.5b highlights states that recorded lower lifespan inequality than the national level over the entire period. Among the states, Mississippi has consistently had the highest lifespan inequality (Figure 2.5a), while Massachusetts and Minnesota have consistently had the lowest lifespan inequality (Figure 2.5b).

Figure 2.5a: Overall trends in Lifespan inequality by State and highlights for selected States - Total Population



Source: Authors' calculations based on the US Human Mortality Database

Figure 2.5b: Overall trends in Lifespan inequality by State and highlights for selected States - Total Population

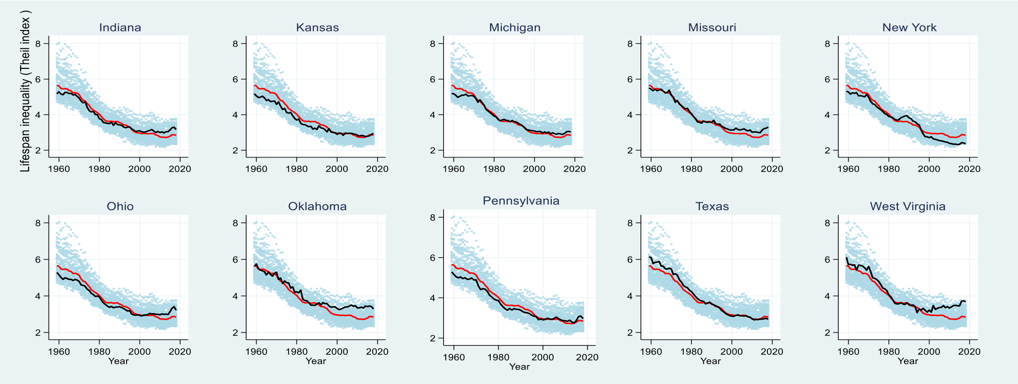


Source: Authors' calculations based on the US Human Mortality Database

As depicted in Figure 2.5c, some states (Indiana, Missouri, Michigan, and Ohio) had below-average lifespan inequality at the beginning of the period under review, but above-average lifespan inequality after the 1990s. In particular, Indiana and Ohio experienced a substantial increase in lifespan inequality after 2010 (Figure 2.5c), as well as significant decreases in life expectancy and increases in mortality.

Moreover, some States, such as New York, maintained a low level of lifespan inequality until the 1980s; since then, it has increased, but it has remained below the national average since 2000 (Figure 2.5c). On the other hand, other states, including West Virginia and Oklahoma showed a decreasing trend, experiencing substantial increases in lifespan inequality after the 1990s and have remained above the US average lifespan inequality (Figure 2.5c).

Figure 2.5c: Overall trends in Lifespan inequality by State and highlights for selected States - Total Population

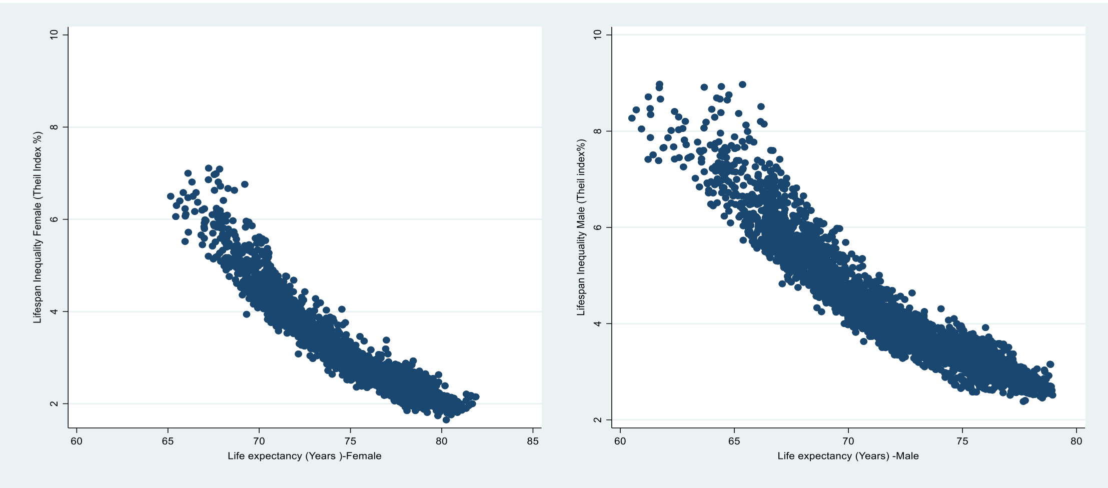


Source: Authors' calculations based on the US Human Mortality Database

Sex Differences in Life Expectancy and Lifespan Inequality by State

As shown in Figure 2.6, the relationship between lifespan inequality and life expectancy becomes even more apparent when life expectancy is plotted against the lifespan inequality for all state-year combinations. Both males (right panel of Figure 6, r = -0.94) and females (left panel of Figure 6, r = -0.95) exhibit a very substantial negative correlation between life expectancy and lifespan inequality. In addition, the figure illustrates that at each level of life expectancy, there exists a range of levels of lifespan inequality across states.

Figure 2.6: State-level lifespan inequality by life expectancy for females and males



Source: Authors' calculations based on the US Human Mortality Database

Regression Results

Table 2.2 presents the results of the PCSE estimations, with total lifespan inequality (Model 1), lifespan inequality for females (Model 2), and lifespan inequality for males (Model 3) as dependent variables. The sample size is reduced to 1350, as some variables are measured in the first differences. However, all three models have relatively high R-squared values, demonstrating that they explain a large proportion of the variation in lifespan inequality.

Table 2.2: Panels Corrected Standard Error Model Results (PCSEs)

Variable	**Model 1** **Lifespan inequality - Total**	**Model 2** **Lifespan inequality - Female**	**Model 3** **Lifespan inequality – Male**
	Coefficient (Standard error)	Coefficient (Standard error)	Coefficient (Standard error)
% high school graduates	-1.100 (<0.001)***	-1.087 (<0.001)***	-1.211 (<0.001)***
% college graduates	-1.140 (<0.001)***	-0.879 (0.002)***	-1.420 (<0.001)***
Gini index	0.750 (0.077)*	0.771 (0.089)*	0.797 (0.151)
Violent Crime rate (per 10000 population)	0.008 (<0.001)***	0.006 (<0.001)***	0.010 (<0.001)***
Cigarette consumption (Pack Sales Per Capita)	0.003 (<0.001)***	0.002 (<0.001)***	0.003 (<0.001)***
Total Personal Health care (% GDP)	0.016 (0.151)	0.008 (0.523)	0.025 (0.085)*
Physicians (per 10000 population)	-0.015 (<0.001)***	-0.012 (<0.001)***	-0.018 (<0.001)***
% insurance prevalence under 65	-0.004 (0.061)*	-0.004 (0.061)*	-0.005 (0.075)*
Population growth	-0.027 (0.007)***	-0.031 (0.003)***	-0.038 (0.003)***
% Black population	-0.026 (0.490)	-0.042 (0.313)	-0.010 (0.832)
% Hispanic population	-0.014 (0.076)*	-0.015 (0.115)	-0.020 (0.104)
CO_2 emissions per capita	0.001 (0.032)**	0.001 (0.175)	0.001 (0.234)
Population density	-0.003 (0.426)	-0.005 (0.184)	0.0001 (0.975)
Unemployment	-0.002 (0.717)	0.0003 (0.955)	0.0004 (0.959)

% of employees in manufacturing	0.001 (0.678)	0.001 (0.722)	-0.004 (0.228)
Real per capita income (Log)	0.413 (0.469)	0.763 (0.214)	0.185 (0.811)
Constant	4.113 (<0.001)***	3.553 (<0.001)***	4.669 (<0.001)***
R-squared	0.885	0.808	0.848
Sample Size	1350	1350	1350

Notes:
Standard errors are reported in parentheses. *Variable names in italics indicate that they are measured in first differences.*
***, ** , * indicate significance at the 1%, 5% and 10% levels respectively.

Education is one of the important predictors in our model. One standard deviation (0.05) increase in the percentage of high school graduates is associated with a 0.054 unit decrease in total lifespan inequality (compared with a mean value of 3.08), and 0.053 unit and 0.06-unit lower lifespan inequality for females and males, respectively. Similar sized effects are demonstrated for the percentage of college graduates. Individuals with a higher level of education generally have greater access to material and nonmaterial resources, facilitating access to healthcare as well as being associated with healthier lifestyles and environments (Link & Phelan, 1995). This suggests that populations with a greater capacity to optimize health over the life course have a more uniform distribution of age at death (Brown et al., 2012). Moreover, the importance of education in explaining state-level differences in lifespan inequality is consistent with previous research that shows, on average, Americans with a college education live longer and exhibit a greater compression of mortality, with fatalities narrowly concentrated at the upper tail of the age distribution, a pattern that is also observed in many European countries (van Raalte et al., 2011). Our results in terms of the importance of education are also consistent with the extant literature on lifespan inequality. Edwards and Tuljapurkar (2005) observed that income or education accounted for a 10 to 15% of the difference in lifespan variation (for those aged 10+ years) in the US. Brown et al. (2012) examined old age mortality compression along socioeconomic dimensions in the US, revealing a positive association between education and mortality compression. Mortality was more compressed among women within each educational group than males. Additionally, Shkolnikov et al. (2003) identified larger lifespan inequality among less educated Russians (ages 20 to 65), with differences by educational group widening between 1979 and 1989.

There is less evidence that income matters in our analysis, after controlling for other state-level factors, with GDP per capita statistically insignificant for all three models. However, income inequality, as measured by the Gini index, is a weak predictor of lifespan inequality in total and for females (significant at the 10 percent level). A one standard deviation (0.04 point) increase in the Gini index is associated with total and female lifespan inequality that are 0.027 and 0.028 units higher, respectively. High income inequality has been associated with increased health risk behaviors like smoking, obesity, and exercise (Chetty, 2016). Furthermore, higher income inequality is significantly associated with rates of low birth weight, homicide, violent crime, low expenditures on medical care and access, all of which led to higher mortality (Kennedy et al, 1996). Thus, higher income inequality is likely to be associated with greater disparities in mortality rates, leading to greater lifespan inequality.

One standard deviation (22.38 per 10,000 population) increase in the violent crime rate is associated with a 0.18-unit higher total lifespan inequality, while one standard deviation (31.62 packs per capita-year) increase in cigarette consumption is associated with 0.095 units higher total lifespan inequality. Our findings on violence are in accord with earlier research showing a positive association between lifespan inequality and the violent crime rate in Venezuela (Garcia and Aburto, 2019) and in Mexico (Aburto and Beltrán-Sánchez, 2019). Even though smoking prevalence has declined in the US, trends in smoking prevalence are highly differentiated geographically and smoking rates have been identified as a significant contributor to the divergence in mortality across US regions (Fenelon, 2013). Peak smoking-attributable mortality trails behind peak smoking consumption by about 30 years at the population level (Lopez et al., 1994), meaning that in spite of decreasing rates of smoking, smoking-related mortality will continue to affect life expectancy and lifespan inequality for many years. According to a long-running prospective British cohort study of medical doctors (Doll et al., 2005), lifelong smokers die on average ten years earlier than nonsmokers. According to Peto et al. (2006), smoking contributed to 29% of male deaths and 27% of female deaths in the US between the ages of 35 and 69 in 2000. Preston et al. (2010) reported comparable statistics across many countries and demonstrated that, among twenty developed nations in 2003, the US had the highest deaths attributable to smoking among females and the sixth highest proportion among males.

Although personal healthcare expenditure is not statistically significant (except for in the model for male lifespan inequality at the 10 percent level), other healthcare variables are significantly related to lifespan inequality. The negative relationship between lifespan inequality and physician density is consistent with negative relationships between physician supply and mortality rates reported for the US (Kindig et al.,2002), as well as between mortality rates and the supply of primary care physicians (Starfield et al., 2005). Health insurance prevalence is also associated with lower lifespan inequality. Health insurance facilitates access to health care services and provides financial protection against the high costs of illness. Insured Americans are more likely to obtain recommended screening and treatment for chronic conditions (Ayanian et al., 2000), and are less likely to suffer from undiagnosed chronic conditions (Ayanian et al., 2003) or to receive substandard medical care, compared to those without health insurance (Committee on the Consequences of Uninsurance, 2002). Furthermore, lack of health insurance increases the likelihood of mortality from certain diseases (Franks et al.1993; McWilliams et al.,2004 and Wilper et al.,2009). For example, more than twice as many Americans aged 25 to 64 died due to lack of health insurance in 2006 than were murdered

(Tanne, 2008). There is significant geographic variation in health insurance coverage (Stone et al., 2015). Moreover, medical insurers offer various schemes with different terms and conditions, which can lead to unequal benefits distribution among beneficiaries, and consequently variation in lifespan inequality.

Population growth is negatively associated with lifespan inequality in all three models. Short term population growth depends on migration, and migrants tend to be younger than the native-born population, as well as healthier – a phenomenon known as the 'healthy migrant' effect (Razum et al., 2000; Newbold, 2006). A healthier population on average, as a result of migration, will also exhibit lower lifespan inequality.

2.4 Conclusion

In this study, we investigated trends over the last 55 years in life expectancy and lifespan inequality in the US, as well as the factors associated with state-level lifespan inequality. The analyses demonstrate compression of mortality over time, in which the distribution of deaths has shifted rightward toward older ages and become increasingly compressed around a rising late-life modal age at death. This is manifested in decreasing lifespan inequality over time. However, the general trend masks substantial heterogeneity in the experiences of different states, particularly in recent years where increases in life expectancy, and decreases in lifespan inequality, have ceased in some Midwest states. Moreover, some states, such as Mississippi, Massachusetts, and Minnesota, exhibit noteworthy departures from the national level of lifespan inequality. Mississippi has continuously had the greatest lifespan inequality, while Massachusetts and Minnesota have consistently had among the lowest levels of lifespan inequality.

Investigating the factors associated with lifespan inequality at the state level, we found that lifespan inequality is correlated with a number of socioeconomic, demographic, and health-related variables, in particular education, income inequality, violent crime, cigarette consumption, and the population growth rate. While not necessarily causal, the relationships we identify may have significant policy ramifications. In particular, risk factor-focused policies and initiatives (such as tobacco taxation, state laws on gun ownership, and health resources allocation) can potentially reduce geographic disparities by enhancing health and safety in all areas, particularly among those currently most disadvantaged. This is not to say that policies that focus on the socioeconomic factors that cause disparities would not be successful; instead, it is to suggest various pathways to more equitable health outcomes for federal, state, and local policymakers should be considered. Moreover, experts now understand that socioeconomic status and health links reflect causal pathways in both directions (Bloom & Canning, 2000). Therefore, policies that address health inequalities may, over time, also be effective means of addressing inequalities in socioeconomic status.

Education was the socio-economic factor that had the greatest relationship with lifespan inequality in our analysis. Health insurance provision was also found to be an important factor associated with lifespan inequality. Disparities in public health insurance provision may be among the most significant policy differences between states. The two age categories whose mortality rates have continued to decrease in the US have been those with complete public health care coverage: the elderly and the very young (Cha & Cohen,2022). While millions have gained health insurance after the passage of the Affordable Care Act in 2010, these gains have since been eroded due to changes to the Medicaid program (which covers low-income Americans) that have made it increasingly difficult for people to enrol and maintain coverage (Ayanian et al, 2000; Wilper et al., 2009). Increasing insurance coverage and removing barriers to access the insurance may contribute to reducing lifespan inequality by improving health among the young and mid-life populations.

It is important to recognize specific limitations in the study of health inequality. A significant limitation is the sole emphasis on mortality, without a thorough analysis of morbidity and the quality of life in terms of health (Permanyer et al., 2022). Our research has not examined the relationship between health inequality and two important aspects of health: morbidity, which refers to the occurrence of illnesses or diseases in a community, and quality of life (QoL). Future study could extend lifespan inequality to a consideration of *healthy lifespan inequality*, incorporating not only mortality but also quality of life considerations. Notwithstanding these issues, our study provides an important contribution to our understanding of lifespan inequality in the US by examining trends over a considerable period of state-level variations. This study may serve as a foundation for policymakers and assist in directing endeavors to formulate policies and treatments that aid in the objective of diminishing lifespan inequality and promoting the overall health and well-being of population groups. Lifespan inequality remains an underutilized metric of health outcomes, and this study provides important insights that, we hope, can be used to steer future research endeavors.

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Appendix

Table A1: Fixed and Random Effects Models

Variable	Model 1 Lifespan inequality -Total (Coef.)		Model 2 Lifespan inequality-Female (Coef.)		Model 3 Lifespan inequality-Male (Coef.)	
	FE	RE	FE	RE	FE	RE
% of high school graduates	-0.168 (0.462)	-0.075 (0.744)	-0.045 (0.834)	0.012 (0.955)	-0.257 (0.383)	-0.157 (0.592)
% of college graduate	0.543 (0.08)*	-1.306 (0.001)***	-0.918 (0.002)***	-1.552 (0.001)***	-0.214 (0.593)	-1.093 (0.003)***
Gini index	0.479 (0.006)***	0.411 (0.002)**	0.039 (0.814)	-0.013 (0.935)	0.834 (0.001)***	0.757 (0.001)***
Violent Crime rate (per 10000 population)	0.0006 (0.001)***	0.0008 (0.001)***	0.004 (0.001)***	0.005 (0.001)***	0.008 (0.001)***	0.01 (0.001)***
Cigarette Consumption (Pack Sales Per Capita)	0.002 (0.001)***	0.002 (0.001)***	0.001 (0.001)***	0.001 (0.001)***	0.002 (0.001)***	0.002 (0.001)***
Total Personal Health care (% GDP)	-0.008 (0.065)*	-0.006 (0.152)	-0.004 (0.321)	0.00003 (0.994)	-0.01 (0.099)*	-0.006 (0.206)
Physicians(per 10000 population)	-0.011 (0.001)***	-0.01 (0.001)***	-0.007 (0.022)**	-0.009 (0.001)***	-0.014 (0.001)***	-0.013 (0.001)***
% of insurance prevalence under 65	0.015 (0.001)***	0.012 (0.001)***	0.011 (0.001)***	0.008 (0.001)***	0.018 (0.001)***	0.015 (0.001)***
Population growth	-0.012 (0.064)*	-0.009 (0.167)	-0.015 (0.012)**	-0.014 (0.019)**	-0.01 (0.219)	-0.005 (0.522)
% of Black population	-0.008 (0.298)	0.016 (0.000)***	0.007 (0.297)	0.016 (0.000)***	0.009 (0.343)	0.018 (0.000)***
% of Hispanic population	-0.02 (0.001)***	-0.01 (0.001)***	-0.012 (0.001)***	-0.005 (0.002)***	-0.026 (0.001)***	-0.011 (0.001)***
Co_2 per capita	-0.0003 (0.723)	0.0001 (0.248)	0.0001 (0.923)	0.001 (0.168)	-0.001 (0.597)	0.001 (0.290)
Population density	-0.004 (0.001)***	-0.001 (0.001)***	-0.004 (0.001)***	-0.001 (0.005)***	-0.004 (0.001)***	-0.001 (0.010)***

Unemployment rate	0.0077	0.004	0.003	-0.001	0.01	0.006
	(0.014)***	(0.180)	(0.305)	(0.829)	(0.012)**	(0.143)
% of employees in manufacturing	-0.004	-0.005	-0.002	-0.002	-0.008	-0.009
	(0.270)	0.162	(0.548)	(0.456)	(0.085)*	(0.019)**
Real Per Capita Income (Log)	-0.882	-0.988	-0.371	-0.467	-1.09	-1.34
	(0.001)***	(0.001)***	(0.019)**	(0.001)***	(0.001)***	(0.001)***
Constant	5.839	6.368	3.777	4.055	7.081	7.994
	(0.001)***	(0.001)***	(0.001)***	(0.001)***	(0.001)***	(0.001)***
Heteroscedasticity test		0.000		0.000		0.000
Serial correlation test		0.000		0.042		0.000
R-squared	0.789	0.768	0.683	0.768	0.745	0.746
Sample Size		1400		1400		1400

*** p<.01, ** p<.05, * p<.1

Source: Authors' calculations

Table A2: Cross-sectional dependence test

Test	Statistic	Prob.
Prob Breusch-Pagan's LM	6145.062	0.000
Pesaran's scaled LM	104.8551	0.000
Pesaran's CD	56.69722	0.000

Source: Authors' calculations

Table A3: Second Generation Unit root test

Variable	CADF		CIPS	
	I(0)	I(I)	I(0)	I(I)
Theil index	-2.637***	-4.643***	-3.623***	-5.931***
Male T	-2.867 ***	-4.747***	-3.842 ***	-5.915***
Female T	-3.014***	-4.975***	-4.219***	-6.030***
% of high school graduates	-2.653***	-4.449***	-2.957***	-5.579 ***
% of college graduate	-2.819***	-4.499***	-3.207***	-5.589***
Gini index	-2.023 ***	-2.954***	-1.943	-4.349 ***
Violent Crime rate(10000 per population)	-2.172***	-3.739***	-2.978***	-4.877***
Cigarette Consumption (Pack Sales Per Capita)	-2.003***	-3.808***	-2.416***	-5.166***
Total Personal Health care (% GDP)	-1.576	-3.396***	-1.463	-4.520***
Physician (10000 per population)	-1.862	-3.820***	-2.526 ***	-5.651***
% Insurance prevalence under 65	-2.292***	-4.759***	-2.900 ***	-5.821***
Population growth	-2.682***	-3.313***	-2.655***	-4.670***
% Black population	-1.126	-2.451***	-0.942	-3.039***
% Hispanic population	-1.444	-2.285***	-2.109*	-4.232***
Co_2 per Capita	-2.583***	-5.429***	-3.543 ***	-6.074***
Population density	-2.368***	-2.533***	-1.269	-2.558 ***
Unemployment rate(%)	-2.428***	-3.327***	-2.364***	-4.073***
% Employees in manufacturing	-2.186***	-2.937***	-2.222 ***	-3.878 ***
Log Real Per Capita income	-2.107***	-2.735***	-1.824	-3.958 ***

Source: Authors' calculations

*** , * indicate significance at the 5% and 10% levels

Chapter 3: The Impact of Homicide on State-Level Life Expectancy and Lifespan Inequality in the US, 1968–2020

Abstract

While life expectancy losses due to homicide are well-documented in the US, their simultaneous effect on lifespan inequality remains underexplored. Therefore, this study examines the impact of homicide on life expectancy and lifespan inequality at the state level in the US from 1968 to 2020, employing Theil's entropy index to measure lifespan inequality. Using a Panel-Corrected Standard Errors (PCSE) econometric model, we also analyzed the demographic, socioeconomic, and policy factors influencing these outcomes. We found substantial regional disparities, with Southern states consistently exhibiting the highest life expectancy losses and lifespan inequality increases due to homicide. Demographic factors, such as a higher proportion of high school graduates, are associated with reduced impacts of homicide, while higher percentages of Black populations and percentage of population 25-34 age group correlate with larger effects, reflecting systemic inequities in exposure to violence. Furthermore, corrections and judicial spending influence both life expectancy and lifespan inequality. Police and health spending mitigate lifespan inequality, while welfare expenditures often correlate with higher inequality, likely reflecting underlying socioeconomic vulnerabilities. Our results emphasize the need for integrated, evidence-based policy approaches targeting structural inequalities and specific demographic vulnerabilities. Strategies such as youth violence prevention, education-focused interventions, and community-based justice reforms are likely to be critical for mitigating homicide's impact. This work underscores homicide's dual role as a public health and societal challenge, calling for tailored policies to address both immediate and systemic factors driving violence.

Keywords

Lifespan inequality

Theil index

Homicide

Socioeconomic factors

United States

3.1 Introduction

The homicide rate in the US has fluctuated significantly over the decades, shaped by various social, economic, and political factors. During the early 1980s, homicide rates peaked at over 10 per 100,000 people, followed by a notable decline beginning in the mid-1990s and continuing into the early 2000s (Levitt, 2004; Blumstein et al., 2000; Cooper & Smith, 2011). However, recent years have seen a resurgence in violent crime, particularly homicides. In 2020, the US experienced a nearly 30% increase in homicides, the largest single-year increase ever recorded (Zimmerman et al., 2024). Regionally, from 2019 to 2020, homicide rates increased in 46 states, with only Alaska, Maine, New Hampshire, and New Mexico reporting declines (Petrosky et al., 2020). This resurgence underscores ongoing challenges in addressing violent crime effectively, with the US consistently ranked as having among the highest homicide rates across developed nations (Riedel & Dirks, 2022).

Some studies have explored the prevalence and distribution of homicide rates, revealing critical insights into racial disparities, geographic variation, and other influencing factors (Buyukozturk et al., 2018; Gobaud et al., 2022; Zimmerman et al., 2024). Key determinants such as age, race or ethnicity, and firearm laws are frequently analyzed to better understand the dynamics of homicide rates (Cooper & Smith, 2011; Rosenfeld & Fox, 2019; Kalesan et al., 2016). For instance, Blumstein (1995) and Cooper & Smith (2011) found that homicide rates are disproportionately higher among adolescents and young adults and that Black/African American communities experience higher homicide victimization rates compared with White populations (Cooper & Smith, 2011; Rosenfeld & Fox, 2019). Studies also indicate that comprehensive firearm regulations are generally associated with lower firearm-related homicide rates (Kalesan et al., 2016; Wintemute, 2015).

A growing body of literature highlights that the consequences of homicide extend far beyond the immediate loss of life, leaving profound social, psychological, and economic impacts on victims' families and communities. For instance, Chapman and Dixon-Gordon (2007) noted that bereaved family members often face psychological distress, including depression, anxiety, anger, and guilt. These effects can manifest in social and behavioural challenges such as aggression, suicidal ideation, and difficulties in school or the workplace. Financially, the economic burden of homicide including funeral costs, medical expenses, criminal justice expenditures, and losses in productivity falls heavily on survivors, employers, and taxpayers. For example, in 2019, the estimated economic cost of fatal injuries from homicides and suicides in the U.S. was $670 billion (Peterson et al., 2021). Additionally, homicide can have a substantial impact on life expectancy. For example, increases in violence-related deaths among young men (ages 15–39) have slowed gains in male life expectancy in Venezuela (García and Aburto, 2019) and Mexico (Aburto and Beltrán-Sánchez, 2019).

While life expectancy provides valuable insights into population health, it can often mask underlying disparities in the distribution of the length of life (Wijesinghe et al., 2024). Lifespan inequality, or variability in age at death, offers a critical perspective by highlighting health disparities and vulnerabilities that life expectancy may fail to capture. Greater lifespan inequality reflects heightened uncertainty about the timing of death, which carries profound psychological and economic consequences. Edwards (2013) argues that, due to general risk aversion, individuals are often willing to trade potential additional years of life for greater certainty regarding their lifespan. When lifespan inequality diverges across socioeconomic groups, it underscores a less-discussed dimension of inequality: those from privileged backgrounds can plan their lives with more confidence, while disadvantaged groups face greater unpredictability in survival. This uncertainty complicates key life decisions, including education, employment, and retirement planning (Brown et al., 2012). For individuals with greater uncertainty, preparing for the future becomes a more stressful and complex process.

At the societal level, lifespan inequality reveals the heterogeneity of health outcomes within a population. High inequality indicates that distinct segments of society experience vastly different health realities. This information is critical for designing effective public policies. From a public health perspective, rising lifespan inequality signals the ineffectiveness of measures intended to protect populations from adverse outcomes. In the context of homicide, increased lifespan inequality may highlight the failure of social protection policies to reduce violent crime and safeguard vulnerable groups.

Despite its importance, the intersection of lifespan inequality and homicide has received limited scholarly attention. Notable exceptions include García and Aburto (2019), who examined the relationship in Venezuela, and Aburto and Beltrán-Sánchez (2019), who conducted a similar study in Mexico, both identifying that increases in homicide contributed significantly to rising lifespan inequality. These findings emphasize the need to explore this relationship further, particularly in contexts where homicide is a significant public health concern, such as in the US. While the impact of homicides on life expectancy and potential years of life lost is well documented at the national level in the US, less is known about the effects of homicide simultaneously on life expectancy and lifespan inequality at the state level.

Therefore, our research addresses two key questions:

1. What is the impact of homicide on life expectancy and lifespan inequality at the state level in the US?
2. What are the socioeconomic and demographic determinants of the impact of homicide on life expectancy and lifespan inequality?

Through this analysis, this article makes two main contributions. First, it advances the literature on life expectancy and lifespan inequality by emphasizing the role of homicide in shaping these outcomes. While most extant studies focus on social determinants of health, such as socioeconomic status or educational attainment, this study highlights how homicide mortality directly affects lifespan inequality and life expectancy. By analyzing these relationships by sex at the state level, this research provides critical insights for policymakers in the US and other nations struggling with similar challenges. Second, this analysis deepens our understanding of lifespan inequality at the regional level, revealing variations across states and the broader implications of these disparities. Policymakers and researchers must recognize that addressing lifespan inequality is not just a health imperative but also a societal one, as it reflects underlying vulnerabilities and inequities.

The remainder of the paper is organized as follows. Section 2 describes the data and provides a brief explanation of the methods. Section 3 presents the results and analysis of the econometric model. The final section concludes.

3.2 Data and Methods

The data on life expectancy and lifespan inequality were sourced from the US Mortality Database (USMDB), which provides comprehensive life tables by sex for all 50 states and the District of Columbia from 1968 to 2020, with age-specific mortality rates extending to age 110. However, initial analyses identified the District of Columbia as an outlier due to its unique patterns in homicide mortality and distinct socioeconomic and demographic characteristics compared to other states (Wijesinghe et al., 2024). Consequently, the District of Columbia was excluded from this study.

Data on homicide deaths were obtained from the National Center for Health Statistics (NCHS) at the Centers for Disease Control and Prevention (CDC). Homicide causes of death were classified according to the International Classification of Diseases (ICD), with classifications evolving across different revisions:

- ICD-8 (1968–1978): Homicide coded as E960–E978.
- ICD-9 (1979–1998): Homicide coded as E960–E969.
- ICD-10 (1999–2020): Homicide coded as X85–Y09 and Y87.1.

State government spending data were sourced from the Government Finance Database, a comprehensive repository derived from the US Census Bureau's Annual Survey of State and Local Government Finances, covering data from 1967 onward. Spending categories analyzed in this study included: Juridical and legal services; Health; Library services; Education; Police; Public welfare; Unemployment; and Correctional expenditures. All financial data were adjusted to 2017 dollars using the implicit price deflator and converted into per capita spending. Population data including total population, racial composition (Black and White populations), and the population percentage in age groups 15–24 and 25–34 were obtained from the US Census Bureau. Income data were sourced from the Federal Reserve Bank of St. Louis FRED database, while state-level income inequality data, including the Gini coefficient, were drawn from the US State-Level Income Inequality Database. Educational attainment measures, specifically the percentages of high school and college graduates in the population, were derived from a database developed by Frank (2009). Per capita alcohol consumption (in gallons) data were obtained from the National Institute on Alcohol Abuse and Alcoholism. Additionally, three dummy variables were created to capture relevant gun control laws at the state level. The first variable is the No Stand-Your-Ground Law (1 = law provision is present, 0 = law provision is absent). This law does not allow individuals to use deadly force to defend themselves if they feel threatened, without the obligation to retreat. The second variable is the Permit to Purchase Law (1 = Yes, 0 = No), which requires individuals to obtain a permit before purchasing a firearm. The third variable is the Universal Background Checks Law (1 = Yes, 0 = No), which mandates that all gun buyers, whether purchasing from a licensed dealer or a private seller, must undergo a background check to ensure they are not prohibited from owning a firearm. The data for these three variables were obtained from the RAND Corporation firearms law database (Cherney et al., 2020). Descriptive statistics for the independent variables are given in Table 3.1. This panel data consists of annual observations for 50 states over the period 1980-2020.

Table 3.1: Descriptive statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
% of Black Population	2050	0.1	0.09	0	0.38
% of White Population	2050	0.84	0.12	0.3	0.99
% Age Group (15-24)	2050	0.15	0.02	0.11	0.2
% Age Group (25-34)	2050	0.15	0.02	0.11	0.24
% of High School Graduate	2050	0.6	0.06	0.39	0.75
% of College Graduate	2050	0.17	0.05	0.07	0.31
Per Capita Corrections Expenditure ($)	2050	139.05	70.28	17.6	578.63
Per Capita Education Expenditure ($)	2050	1742.98	644.23	410.3	4879.75
Per Capita Judicial Expenditure ($)	2050	67.03	53.97	4.42	405.85
Per Capita Health Expenditure ($)	2050	177.1	112	25.96	942.81
Per Capita Library Expenditure ($)	2050	5.09	5.42	0	52.35
Per Capita Police expenditure ($)	2050	47.78	30.75	2.53	253.84
Per Capita Public Welfare Expenditure ($)	2050	1203.06	668.97	142.28	3889.93
Per Capita Unemployment allowances Expenditure ($)	2050	160.32	121.47	13.82	1000.62
Universal Background Checks Law	2050	0.18	0.39	0	1
Permit to Purchase Law (Gun)	2050	0.23	0.42	0	1
No Stand Your Ground Law (Gun)	2050	0.84	0.37	0	1
Unemployment Rate (%)	2050	5.83	2.12	2.1	18
Per Capita Income ($thousands)	2050	38101.06	9874.84	18414.98	74361.95
Gini Coefficient	2050	0.57	0.05	0.45	0.73
Per capita alcohol consumption (gallons)	2050	2.43	0.56	1.19	5.75
Population Density (per square mile)	2050	181.81	248.86	0.71	1260.77

Source: Authors' calculations

Demographic and Statistical Techniques

This study uses life table and cause-eliminated life table methods to estimate how homicide affects life expectancy and lifespan inequality (Arias et al., 2013). The process begins with calculating survival probabilities (${}_np_x$) from the all-cause life tables, as follows:

$$ {}_n\boldsymbol{p}_x = \mathbf{1} - {}_n\boldsymbol{q}_x \tag{1} $$

where x is the exact age, n is the number of years in the age interval, and ${}_nq_x$ is the probability of dying between the beginning of an age interval and before reaching the end of that age interval.

The next step involves estimating the probability of death after removing homicide($_nq_{x1}{}^{(-i)}$), using the following formula.

$$ {}_n\boldsymbol{q}_{\boldsymbol{x}_1}^{(-i)} = \mathbf{1} - {}_n\boldsymbol{p}_{\boldsymbol{x}}\left(\frac{{}_n\boldsymbol{D}_{\boldsymbol{x}} - {}_n\boldsymbol{D}_{\boldsymbol{x}}\boldsymbol{i}}{{}_n\boldsymbol{D}_{\boldsymbol{x}}}\right) \quad (2)$$

where $_nD_x$ is the number of deaths in the age interval x to $x + n$ for all causes, and $_nD_x{}^i$ is the number of deaths in the age interval x to $x+n$ attributable to homicide.

Next, the number of person-years lived $_nL_{x1}{}^{(-i)}$ in the age interval x to $x+n$ was estimated for ages 0 to 110 using:

$$ {}_n\boldsymbol{L}_{\boldsymbol{x}_1}^{(-i)} = (\boldsymbol{n} - {}_n\boldsymbol{f}_{\boldsymbol{x}}).\boldsymbol{l}_{\boldsymbol{x}}^{(-i)} + {}_n\boldsymbol{l}_{\boldsymbol{x}}..\boldsymbol{l}_{\boldsymbol{x}+\boldsymbol{n}}^{(-i)} \quad (3)$$

where n=1 for all age intervals (x=0,1, 2,…,110) and $_nl_x$ represents the number of individuals from the original life table who survive to the beginning of each age interval, $l_x{}^{(-i)}$ denotes the number of survivors from the life table after eliminating deaths due to homicide, L_x is the number of person-years lived within a specific age interval x to $x+n$ and $_nf_x$ represents the force of mortality (probability of death) for the age interval and is estimated from the all-cause life table, using:

$$ {}_n\boldsymbol{f}_{\boldsymbol{x}} = \frac{\boldsymbol{n}\cdot{}_n\boldsymbol{l}_{\boldsymbol{x}} - {}_n\boldsymbol{L}_{\boldsymbol{x}}}{\boldsymbol{l}_{\boldsymbol{x}} - \boldsymbol{l}_{\boldsymbol{x}+\boldsymbol{n}}} \quad (4)$$

The last step is to calculate the number of person-years lived after the exact age x ($T_x{}^{(-i)}$) using:

$$ \boldsymbol{T}_{\boldsymbol{x}}^{(-i)} = \boldsymbol{L}_{\boldsymbol{x}}^{(-i)} + \boldsymbol{L}_{\boldsymbol{x}+\mathbf{1}}^{(-i)} + \cdots . + \boldsymbol{L}_{\mathbf{110}+}^{(-i)} \quad (5)$$

Finally, the cause-eliminated life expectancy ($e_x{}^{(-i)}$) is calculated as follows:

$$ \boldsymbol{e}_{\boldsymbol{x}}^{(-i)} = \frac{\boldsymbol{T}_{\boldsymbol{x}}^{(-i)}}{\boldsymbol{l}_{\boldsymbol{x}}^{(-i)}} \quad (6)$$

To assess homicide's contribution to changes in life expectancy, we calculate the difference between cause-eliminated life expectancy ($e_x{}^{(-i)}$) and the observed life expectancy e_x in that same year.

The changes in life expectancy were calculated as the difference between life expectancy from the all-cause life table and the homicide elimination life table. The contribution of homicide to life expectancy ranged from 0.05 to 0.64 years for the total population, with a mean of 0.18 (SD = 0.10). For males, the average contribution was 0.26 (SD = 0.16), while for females, it was 0.09(SD = 0.05).

Lifespan inequality measurement - Theil index

In this study, we select the Theil Index to measure lifespan inequality due to its sensitivity to variations across the entire age-at-death distribution. This characteristic makes it more responsive compared to other measures like the Gini Index, which tends to underweight the importance of higher values, crucial for lifespan analysis. Lifespan inequality is calculated for the total population as well as males and females separately.
The Theil Index for lifespan inequality is denoted as T_a can be computed using the following formula:

$$\boldsymbol{T_a = \frac{1}{l_a}\sum_{x=a}^{\omega} d_x \left(\frac{\alpha_x}{\mu_a}\right) log \left(\frac{\alpha_x}{\mu_a}\right)} \tag{7}$$

where a and ω are the youngest and oldest age intervals taken from a given life table, l_x is the radix of the population, μ_a is the average age at death of the population, and d_x and α_x are the life table number of deaths and the average age at death in the age interval x to $x+1$, respectively.

The change in lifespan inequality was calculated as the difference between lifespan inequality from the all-cause life table and the homicide elimination life table using the Theil index. The contribution of homicide to lifespan inequality ranged from -0.01 to 0.75 for the total population, with a mean of 0.1 (SD = 0.09). For males, the average contribution was 0.13 (SD = 0.08), while for females, it was 0.04 (SD = 0.03).

Panel Corrected Standard Error Model (PCSE

The basic econometric specification of the panel regression model is as follows:

$$\boldsymbol{Y_{it} = \beta_0 + \beta_k X_{kit} + U_{it}} \tag{8}$$

where Y_{it} is the change in life expectancy or lifespan inequality due to homicide for state i in period t, X_{kit} is a vector of independent variables, β_{kit} is a vector of coefficients for the independent variables, and U_{it} is the error term and is assumed to be i.i.d. One set of models was estimated to analyze the loss of life expectancy due to homicide, with models for the total population as well as for males and females separately. Another set of models was estimated to assess the contribution of homicide to lifespan inequality, again focusing on the total population, as well as male and female populations separately.

Initially, pooled OLS regression was conducted, followed by determining whether a random effects or fixed effects model was more appropriate using the Hausman test. The test results indicated that the fixed effects model was the best fit for all three models of life expectancy (total $p<0.001$; male $p<0.001$; female $p<0.001$) and lifespan inequality (total $p=0.028$; male $p<0.001$; female $p<0.001$). Subsequently, fixed effects regression models were estimated, and tests for heteroscedasticity and autocorrelation were carried out using the Wald test and the serial correlation test, respectively. Both tests confirmed the presence of heteroscedasticity and autocorrelation in the panel data (Appendix Tables A1 and A2). To investigate cross-sectional dependence, we used the tests proposed by Pesaran et al., (2004), including the cross-sectional dependence (CD) test, and rejected the null hypothesis of no cross-sectional dependence (Appendix Table A3).

Before estimating the model, we also tested the stationarity of the variables. Since first-generation unit root tests can be biased in the presence of heterogeneity and cross-sectional dependence (Pesaran, 2007), second-generation unit root tests were applied, specifically the cross-sectional ADF (CADF) and cross-sectionally augmented IPS (CIPS) tests. According to the CADF test, population density, per capita expenditure on library and welfare, percentage of college graduates and per capita alcohol consumption (gallons) were all stationary in first differences, while others were stationary in both levels and first differences (see Appendix Table A4). The CIPS test indicated that the percentage Black Population, percentage White Population, per capita alcohol consumption (gallons), percentage of college graduates and population density had unit roots but became stationary after first differencing (Appendix Table A4).

To address issues such as heteroscedasticity, serial correlation, and cross-sectional dependence in the data, the Feasible Generalized Least Squares (FGLS) method is generally recommended, as noted by Wooldridge (2010). However, Beck and Katz (1995) advocate for using OLS with heteroscedasticity-corrected standard errors (OLS-PCSE) when analyzing cross-sectional time-series data, since the standard errors obtained from FGLS may underestimate the variability of the estimates. The OLS-PCSE method tends to offer more reliable standard error estimates and performs better in such situations, as demonstrated in their Monte Carlo simulations. FGLS is more suitable for panels where the number of time periods (T) exceeds the number of cross-sectional units (N), whereas the PCSE estimator is more appropriate when the number of periods is smaller than the number of cross-sectional units. Given that our sample includes 40 time periods and 50 cross-sectional units, the OLS-PCSE approach should be preferred. Furthermore, the OLS-PCSE method provides robust standard error estimates by addressing heteroscedasticity and contemporaneous correlation across cross-sections, as it adjusts for variations in error variance and potential correlation across units (Reed & Webb, 2010; Bailey and Katz, 2011). Hence, the PCSE estimator is considered the most suitable method for analyzing our panel data.

3.3 Results and Discussion

Table 3.2 provides a breakdown of homicide's contribution to changes in life expectancy for selected years for each state, calculated using the cause-elimination method described in the previous section. Positive numbers in Table 3.2 represent the *decrease* in life expectancy due to homicide. Many states, but particularly those in the South (e.g. Louisiana, Mississippi), West (e.g. New Mexico, Nevada), and Mid-West (e.g. Illinois, Missouri) experienced an increasing impact of homicide on life expectancy from 1968 to 2020. For example, in Louisiana the loss of life expectancy due to homicide increased from 0.33 years in 1968 to 0.42 years in 2000, and to 0.59 years in 2020. The increase was particularly apparent for males, who experienced a life expectancy loss due to homicide that increased from 0.49 years in 1968 to 0.94 years in 2020, although an increase in the loss of life expectancy due to homicide for females is also apparent. States in the Northeast (e.g., New York, Pennsylvania) have generally had lower homicide-related life expectancy losses compared to the South, though there have been slight increases over time in some states. In general, males consistently experienced greater losses in life expectancy due to homicide than females across all states.

Table 3.2: Contribution of Homicide Mortality to Decreases in Life Expectancy at birth (years) by State: 1968, 2000 and 2020

Region	State	Life Expectancy Decrease (1968)			Life Expectancy Decrease (2000)			Life Expectancy Decrease (2020)		
		Total	Male	Female	Total	Male	Female	Total	Male	Female
South	Alabama	0.31	0.48	0.11	0.29	0.43	0.15	0.41	0.67	0.13
	Arkansas	0.22	0.34	0.08	0.23	0.34	0.11	0.37	0.53	0.19
	Delaware	0.18	0.27	0.09	0.08	0.10	0.07	0.33	0.50	0.15
	Florida	0.37	0.52	0.18	0.19	0.27	0.10	0.25	0.38	0.10
	Georgia	0.39	0.53	0.20	0.23	0.31	0.13	0.64	0.51	0.11
	Kentucky	0.23	0.35	0.08	0.14	0.17	0.11	0.27	0.39	0.14
	Louisiana	0.33	0.49	0.11	0.42	0.61	0.19	0.59	0.94	0.20
	Maryland	0.24	0.35	0.09	0.33	0.53	0.09	0.38	0.60	0.12
	Mississippi	0.28	0.44	0.11	0.31	0.42	0.19	0.57	0.89	0.21
	North Carolina	0.27	0.39	0.12	0.24	0.35	0.10	0.27	0.42	0.10
	Oklahoma	0.15	0.24	0.06	0.16	0.23	0.10	0.25	0.37	0.11
	South Carolina	0.33	0.45	0.16	0.24	0.35	0.12	0.39	0.62	0.13
	Tennessee	0.27	0.40	0.10	0.25	0.36	0.12	0.34	0.52	0.12

	Texas	0.32	0.49	0.12	0.19	0.27	0.10	0.23	0.35	0.10
	Virginia	0.23	0.31	0.12	0.19	0.25	0.11	0.21	0.32	0.07
	West Virginia	0.11	0.17	0.05	0.12	0.17	0.06	0.17	0.24	0.09
West	Alaska	0.23	0.36	0.09	0.19	0.29	0.07	0.20	0.24	0.14
	Arizona	0.21	0.25	0.15	0.25	0.35	0.12	0.22	0.32	0.10
	California	0.17	0.23	0.08	0.20	0.30	0.07	0.19	0.30	0.06
	Colorado	0.15	0.20	0.09	0.11	0.19	0.07	0.17	0.19	0.08
	Hawaii	0.08	0.11	0.03	0.07	0.09	0.06	0.10	0.13	0.06
	Idaho	0.08	0.11	0.06	0.05	0.08	0.02	0.06	0.09	0.03
	Montana	0.09	0.08	0.09	0.11	0.15	0.08	0.18	0.25	0.09
	New Mexico	0.15	0.22	0.07	0.27	0.41	0.13	0.30	0.46	0.10
	Nevada	0.16	0.18	0.13	0.20	0.31	0.08	0.21	0.31	0.09
	Oregon	0.08	0.08	0.08	0.08	0.12	0.03	0.12	0.17	0.05
	Utah	0.09	0.09	0.10	0.07	0.08	0.04	0.09	0.12	0.04
	Washington	0.09	0.11	0.06	0.11	0.15	0.06	0.14	0.19	0.07
	Wyoming	0.09	0.07	0.09	0.05	0.06	0.03	0.10	0.14	0.07
North east	Connecticut	0.08	0.10	0.04	0.10	0.15	0.05	0.15	0.23	0.06
	Massachusetts	0.09	0.12	0.04	0.06	0.10	0.03	0.08	0.15	0.01
	Maine	0.03	0.03	0.01	0.04	0.03	0.04	0.05	0.08	0.01
	New Hampshire	0.04	0.01	0.06	0.03	0.05	0.02	0.03	0.04	0.02
	New Jersey	0.13	0.19	0.07	0.13	0.20	0.04	0.15	0.22	0.06
	New York	0.17	0.28	0.07	0.18	0.27	0.07	0.15	0.24	0.05
	Pennsylvania	0.11	0.16	0.05	0.18	0.27	0.08	0.28	0.44	0.08
	Rhode Island	0.06	0.07	0.05	0.12	0.20	0.03	0.09	0.14	0.03
	Vermont	0.04	0.04	0.03	0.03	0.05	0.03	0.07	0.12	-0.01
Mid-West	Iowa	0.05	0.04	0.05	0.07	0.08	0.05	0.10	0.15	0.05
	Illinois	0.22	0.33	0.10	0.27	0.40	0.10	0.37	0.61	0.10
	Indiana	0.15	0.23	0.07	0.20	0.28	0.11	0.30	0.45	0.12
	Kansas	0.10	0.13	0.06	0.17	0.24	0.10	0.22	0.33	0.08
	Michigan	0.21	0.32	0.09	0.23	0.34	0.11	0.26	0.41	0.10
	Minnesota	0.06	0.08	0.03	0.09	0.11	0.06	0.12	0.19	0.05
	Missouri	0.23	0.35	0.09	0.23	0.32	0.12	0.43	0.64	0.18
	North Dakota	0.02	0.03	0.02	0.04	0.07	0.03	0.11	0.16	0.05
	Nebraska	0.05	0.08	0.03	0.12	0.16	0.08	0.12	0.19	0.04
	Ohio	0.16	0.22	0.09	0.12	0.16	0.08	0.29	0.44	0.11
	South Dakota	0.08	0.09	0.07	0.06	0.09	0.01	0.19	0.27	0.08
	Wisconsin	0.06	0.08	0.05	0.11	0.15	0.06	0.20	0.28	0.10
Mean		0.16	0.23	0.08	0.16	0.23	0.08	0.23	0.34	0.09
SD		0.10	0.15	0.04	0.09	0.13	0.04	0.14	0.20	0.05

Source: Authors' calculations. Note: For each year, the absolute impact of homicide on life expectancy is calculated by subtracting the life expectancy after eliminating homicide-related deaths from the life expectancy based on all-cause mortality for that specific year.

Table 3.3 presents the changes in lifespan inequality due to homicide for each state. Positive numbers in Table 3.3 represent the *increase* in lifespan inequality due to homicide, and it is apparent that the impact of homicide is to increase lifespan inequality generally across all states and years. The increase in lifespan inequality due to homicide increased in many states, but particularly those in the South (e.g. Louisiana, Mississippi), West (e.g. New Mexico, Nevada) and Mid-West (e.g. Illinois, Missouri). Generally, the states that have experienced the greatest negative impact on life expectancy due to homicide have experienced the greatest increase in lifespan inequality due to homicide. The Pearson correlation between those two impacts (on life expectancy and lifespan inequality) was 0.98 in 1968, 0.99 in 2000, and 0.94 in 2020. Like life expectancy, the impacts of homicide on lifespan inequality are generally larger for men than for women. Moreover, there are only a few instances where lifespan inequality has decreased due to homicide, among females in states in the Northeast.

Table 3.3: Contribution of Homicide Mortality to Changes in Lifespan Inequality by State: 1968, 2000 and 2020

Region	State	Lifespan Inequality Change (1968)			Lifespan Inequality Change (2000)			Lifespan Inequality Change (2020)		
		Total	Male	Female	Total	Male	Female	Total	Male	Female
South	Alabama	0.13	0.20	0.03	0.15	0.23	0.07	0.21	0.35	0.06
	Arkansas	0.08	0.12	0.02	0.13	0.19	0.06	0.19	0.27	0.10
	Delaware	0.08	0.12	0.04	0.03	0.05	0.02	0.18	0.26	0.08
	Florida	0.16	0.22	0.07	0.09	0.14	0.05	0.13	0.20	0.04
	Georgia	0.17	0.22	0.09	0.12	0.16	0.07	0.16	0.26	0.05
	Kentucky	0.09	0.12	0.03	0.07	0.09	0.05	0.13	0.19	0.07
	Louisiana	0.15	0.22	0.04	0.24	0.33	0.12	0.32	0.50	0.11
	Maryland	0.11	0.16	0.04	0.19	0.31	0.04	0.2	0.31	0.06
	Mississippi	0.10	0.15	0.04	0.16	0.22	0.10	0.29	0.44	0.11
	North Carolina	0.11	0.15	0.04	0.12	0.19	0.04	0.14	0.23	0.05
	Oklahoma	0.05	0.09	0.02	0.08	0.11	0.05	0.11	0.18	0.05
	South Carolina	0.14	0.18	0.07	0.13	0.19	0.06	0.20	0.33	0.06
	Tennessee	0.11	0.16	0.03	0.13	0.19	0.06	0.17	0.27	0.06
	Texas	0.14	1.66	0.05	0.10	0.89	0.05	0.12	1.02	0.05
	Virginia	0.09	0.12	0.05	0.10	0.13	0.06	0.11	0.17	0.03
	West Virginia	0.03	0.06	0.00	0.06	0.08	0.02	0.08	0.11	0.04
West	Alaska	0.09	0.16	0.05	0.13	0.21	0.04	0.08	0.10	0.05
	Arizona	0.09	0.10	0.07	0.13	0.18	0.05	0.11	0.14	0.05
	California	0.07	0.10	0.03	0.11	0.16	0.03	0.08	0.14	0.02
	Colorado	0.06	0.09	0.03	0.05	0.07	0.03	0.08	0.04	0.03
	Hawaii	0.02	0.04	0.00	0.02	0.03	0.02	0.04	0.06	0.04
	Idaho	0.04	0.05	0.02	0.01	0.03	0.00	0.02	0.04	0.00
	Montana	0.03	0.02	0.04	0.05	0.07	0.04	0.09	0.11	0.04
	New Mexico	0.05	0.09	0.02	0.14	0.22	0.06	0.13	0.21	0.04
	Nevada	0.06	0.05	0.06	0.10	0.15	0.04	0.10	0.15	0.04
	Oregon	0.03	0.03	0.03	0.04	0.06	0.00	0.05	0.08	0.01
	Utah	0.04	0.03	0.05	0.03	0.05	0.01	0.03	0.05	0.01

	Washington	0.03	0.03	0.02	0.06	0.09	0.02	0.07	0.10	0.03
	Wyoming	0.02	0.00	0.03	0.02	0.04	0.00	0.03	0.06	0.01
Northeast	Connecticut	0.04	0.04	0.02	0.05	0.08	0.02	0.07	0.12	0.02
	Massachusetts	0.04	0.05	0.01	0.03	0.05	0.01	0.03	0.07	-0.01
	Maine	0.00	-0.01	-0.01	0.01	0.00	0.01	0.01	0.03	0.00
	New Hampshire	0.01	-0.01	0.02	0.01	0.02	0.00	0.01	0.01	0.01
	New Jersey	0.05	0.08	0.03	0.07	0.11	0.02	0.07	0.11	0.02
	New York	0.07	0.13	0.02	0.10	0.15	0.04	0.07	0.12	0.02
	Pennsylvania	0.04	0.08	0.01	0.09	0.15	0.04	0.14	0.23	0.04
	Rhode Island	0.02	0.01	0.03	0.06	0.10	0.02	0.04	0.06	0.01
	Vermont	0.01	-0.01	0.01	0.00	0.01	0.00	0.03	0.05	-0.03
Mid-West	Iowa	0.02	0.00	0.02	0.04	0.05	0.02	0.04	0.06	0.01
	Illinois	0.11	0.17	0.04	0.15	0.22	0.05	0.19	0.32	0.05
	Indiana	0.06	0.10	0.02	0.12	0.17	0.07	0.16	0.24	0.06
	Kansas	0.04	0.06	0.03	0.09	0.12	0.05	0.11	0.17	0.04
	Michigan	0.09	0.14	0.04	0.12	0.18	0.05	0.13	0.22	0.05
	Minnesota	0.02	0.03	0.00	0.04	0.06	0.01	0.06	0.11	0.02
	Missouri	0.09	0.14	0.04	0.13	0.18	0.06	0.23	0.33	0.09
	North Dakota	0.01	0.01	0.00	0.01	0.03	0.02	0.05	0.07	0.01
	Nebraska	0.01	0.03	0.00	0.07	0.09	0.04	0.04	0.08	0.01
	Ohio	0.07	0.10	0.04	0.06	0.08	0.04	0.15	0.24	0.05
	South Dakota	0.02	0.03	0.02	0.03	0.05	0.00	0.09	0.13	0.03
	Wisconsin	0.02	0.02	0.02	0.05	0.08	0.03	0.1	0.14	0.05
Mean		0.06	0.12	0.03	0.08	0.14	0.04	0.11	0.19	0.04
SD		0.04	0.23	0.02	0.05	0.13	0.03	0.07	0.16	0.03

Source: Authors' calculations. Note: For each year, the absolute impact of homicide on lifespan inequality is calculated by subtracting the lifespan inequality after eliminating homicide-related deaths from the lifespan inequality based on all-cause mortality for that specific year.

Table 3.4 presents the results of the PCSE estimations, where the dependent variables are the decrease in life expectancy due to homicide for the total population (Model 1), for males (Model 2), and females (Model 3).

Table 3.4: Determinants of decrease in life expectancy due to homicide (PCSE Model Results)

Variable	Model 1 Decrease in Life Expectancy due to Homicide - Total Population	Model 2 Decrease in Life Expectancy due to Homicide - Male Population	Model 3 Decrease in Life Expectancy due to Homicide - Female Population
	Coef.	Coef.	Coef.
% Black Population	0.931 (<0.001)***	1.356 (<0.001)***	0.292 (<0.001)***
% White Population	-0.025 (0.244)	-0.027 (0.381)	-0.021 (0.106)
% Age Group (15-24)	-0.306 (0.138)	-0.443 (0.164)	-0.323 (0.003)***
% Age Group (25-34)	0.718 (<0.001)***	0.797 (0.002)***	0.665 (<0.001)***
% High School Graduate	-0.338 (<0.001)***	-0.478 (<0.001)***	-0.180 (<0.001)***
% College Graduate	0.086 (0.270)	0.137 (0.253)	-0.103 (0.139)
Per Capita Corrections Expenditure (Log)	0.037 (0.019)**	0.047 (0.040)**	0.041 (<0.001)***
Per Capita Education Expenditure (Log)	-0.033 (0.148)	-0.046 (0.169)	-0.034 (0.200)
Per Capita Judicial Expenditure (Log)	-0.050 (<0.001)***	-0.076 (<0.001)***	-0.019 (0.004)***
Per Capita Health Expenditure (Log)	-0.003 (0.739)	-0.001 (0.934)	-0.006 (0.574)
Per Capita library Expenditure (Log)	-0.003 (0.488)	-0.003 (0.667)	-0.008 (0.018)**
Per Capita Police expenditure (Log)	-0.007 (0.452)	0.001 (0.955)	-0.015 (0.126)

Per Capita Public Welfare Expenditure (Log)	0.033 (0.067)*	0.056 (0.039)	0.013 (0.172)
Per Capita Unemployment allowances Expenditure (Log)	0.012 (0.200)	0.018 (0.230)	-0.002 (0.728)
Universal Background Checks Law (Gun)	0.012 (0.066)*	0.023 (0.023)**	0.0002 (0.948)
Permit to Purchase Law (Gun)	-0.008 (0.268)	-0.002 (0.880)	0.001 (0.841)
No Stand Your Ground Law (Gun)	-0.013 (0.068)*	-0.024 (0.024)**	-0.008 (0.059)*
Unemployment Rate (%)	-0.001 (0.300)	-0.002 (0.469)	0.00004 (0.959)
Real Per Capita Income (Log)	0.008 (0.742)	0.008 (0.840)	0.017 (0.496)
Gini Coefficient	0.011 (0.875)	0.046 (0.672)	-0.064 (0.102)
Per capita alcohol consumption (gallons)	0.004 (0.514)	0.001 (0.923)	0.001 (0.757)
Population Density (per square mile-Log)	-0.016 (<0.001)***	-0.021 (<0.001)***	-0.010 (<0.001)***
Constant	0.233 (0.329)	0.335 (0.358)	0.113 (0.571)
R-squared	0.50	0.43	0.43
Sample Size	2050	2050	2050

Source: Authors' calculations

**** p<0.01, ** p<0.05, * p<0.1*

Demographic factors play a key role in determining the decrease in life expectancy due to homicide in our models. For example, the percentage Black population shows a strong positive association with increased life expectancy losses due to homicide. Specifically, a one-standard deviation (9 percentage point) increase in the percentage of the Black population corresponds to a 0.84 standard deviation (0.08 year) greater decrease in life expectancy for the total population. The corresponding effects for the male and female populations are 0.76 standard deviations for males and 0.53 standard deviations for females. This aligns with research by Pridemore, 2002; Pridemore, 2011; McCall et al., 2011 Rogers & Pridemore, 2013 ;Fleegler et al., 2013; Zimmerman et al.,2024, who found that Black populations are more likely to reside in areas characterized by high poverty and unemployment conditions linked to elevated rates of violent crime. In contrast, white populations have historically benefited from more favourable residential patterns and economic advantages, reducing their exposure to violent crime.

Moreover, the proportion of the population aged 25–34 was statistically significant for all three models. This may be because homicide is concentrated among younger people. For example, it is the third leading cause of death for persons aged 25–34 years (Nguyen et al., 2021). A one-standard-deviation increase (2 percentage points) in the population share aged 25–34 years is associated with a 0.14 standard deviation (0.014 years) increase in homicide related life expectancy loss for the total population. For females, this corresponds to a 0.27 standard deviation (0.013 years) increase, while for males, it corresponds to a 0.10 standard deviation (0.015 years) increase.

Educational attainment demonstrates a significant effect, for high school graduates but not for college graduates. A one-standard-deviation (6 percentage point) increase in the proportion of the population with a high school education is associated with a 0.20 standard deviation (0.020 year) lower decrease in life expectancy due to homicide for the total population, with the corresponding figures for males and females being 0.18 standard deviations (0.028 years), and 0.22 standard deviations (0.010 years), respectively. These findings are consistent with prior work suggesting that high school graduation reduces the probability of incarceration and criminal activity (Lochner and Moretti, 2001).

For public expenditures, a one-standard-deviation increase in per capita corrections spending is significantly associated with an increase in homicide-related life expectancy losses. A one-standard-deviation (23 percentage point) increase in the per capita corrections expenditures is associated with a 0.09 standard deviation (0.008 year) increase in life expectancy lost due to homicide for the total population, with the corresponding figures for males and females being

0.07 standard deviations (0.010 years), and 0.19 standard deviations (0.009 years), respectively. This reflects states with higher crime, and thus higher incarceration rates, having negative impacts of homicide on life expectancy. Further, Hazra and Aranzazu (2022) also found that spending on corrections is linked to an increase in crime rates at the state level. Conversely, per capita judicial expenditures are significantly associated with smaller reductions in life expectancy due to homicide. A one-standard-deviation increase in per capita judicial expenditures is associated with a reduction in homicide-related life expectancy losses of 0.17 standard deviations (0.017 years) for the total population, 0.16 standard deviations (0.025 years) for males, and 0.13 standard deviations (0.006 years) for females.

Firearms policy also appears to have some effect. The absence of Stand Your Ground (SYG) laws is associated with a lesser impact of homicide on life expectancy. Specifically, homicide-related life expectancy losses are 0.013 years lower for the total population, 0.024 years lower for males, and 0.008 years lower for females in the absence of a Stand Your Ground law. These findings align with Cheng and Hoekstra (2013) and Degli Esposti et al. (2022), who both found that SYG laws lead to significant increases in homicide rates.

Finally, population density is associated with statistically significantly lower decreases in life expectancy due to homicide. Specifically, a one standard deviation higher population density is associated with a 0.23 standard deviation (0.022 years) lower decrease in life expectancy for the total population, a 0.19 standard deviation (0.029 years) lower decrease in life expectancy for males, and a 0.28 standard deviation (0.014 years) lower decrease in life expectancy for females. Although it may seem contradictory that more densely populated areas could experience lower homicide-related life expectancy losses, there is empirical evidence that might explain this relationship. For instance, research suggests that urban centres often offer robust institutional structures including higher police presence, faster emergency medical response, and greater social services that can reduce the lethality of violent incidents (Sampson et al., 1997). Moreover, crowded environments typically have more witnesses and surveillance factors that increase the likelihood of crimes being witnessed and quickly reported, thus deterring serious violence or limiting fatalities at the state level in the USA (Piggott, 2015). While it is true that overall levels of non-lethal violent crime may be higher in some urban areas, the combination of quicker medical intervention and more comprehensive law enforcement can help mitigate homicide risk.

Table 3.5 presents the results of the PCSE estimations, where the dependent variables are the change in lifespan inequality due to homicide for the total population (Model 1), for males (Model 2), and females (Model 3). Comparing the results in this table with those in Table 4 reveals both similarities and differences between the factors associated with the impact of homicide on life expectancy, and the factors associated with the impact of homicide on lifespan inequality.

Table 3.5: Determinants of changes in lifespan inequality due to homicide (PCSE model results)

Variable	Model 1 Change in Lifespan Inequality due to Homicide - Total Population	Model 2 Change in Lifespan Inequality due to Homicide - Male Population	Model 3 Change in Lifespan Inequality due to Homicide - Female Population
	Coef.	Coef.	Coef.
% Black Population	0.473 (<0.001)***	0.739 (<0.001)***	0.150 (<0.001)***
% White Population	-0.010 (0.506)	0.008 (0.667)	-0.005 (0.439)
% Age Group (15-24)	-0.161 (0.178)	-0.281 (0.083)*	-0.125 (0.012)**
% Age Group (25-34)	0.346 (0.002)***	0.403 (0.001)***	0.323 (<0.001)***
% High School Graduate	-0.164 (<0.001)***	-0.189 (0.002)***	-0.074 (0.001)***
% College Graduate	-0.011 (0.817)	-0.045 (0.49)	-0.044 (0.099)*
Per Capita Corrections Expenditure (Log)	0.038 (<0.001)***	0.054 (<0.001)***	0.032 (<0.001)***
Per Capita Education Expenditure (Log)	-0.008 (0.611)	-0.024 (0.186)	-0.005 (0.513)
Per Capita Judicial Expenditure (Log)	-0.030 (<0.001)***	-0.045 (<0.001)***	-0.011 (<0.001)***
Per Capita Health Expenditure (Log)	-0.013 (0.024)**	-0.004 (0.614)	-0.012 (<0.001)***
Per Capita library Expenditure (Log)	-0.003 (0.257)	0.002 (0.689)	-0.004 (0.022)**
Per Capita Police expenditure (Log)	-0.015 (0.028)**	-0.020 (0.026)**	-0.008 (0.020)**

Per Capita Public Welfare Expenditure (Log)	0.037 (0.001)***	0.048 (0.001)***	0.010 (0.025)**
Per Capita Unemployment allowances Expenditure (Log)	0.006 (0.277)	0.009 (0.273)	-0.003 (0.240)
Universal Background Checks Law	0.001 (0.873)	0.007 (0.233)	-0.001 (0.680)
Permit to Purchase Law (Gun)	-0.006 (0.250)	-0.003 (0.582)	-0.002 (0.295)
No Stand Your Ground Law (Gun)	-0.007 (0.103)	-0.009 (0.121)	-0.004 (0.062)*
Unemployment Rate (%)	-0.001 (0.138)	-0.001 (0.515)	0.0003 (0.475)
Real Per Capita Income (Log)	-0.009 (0.59)	-0.001 (0.941)	-0.003 (0.669)
Gini Coefficient	0.002 (0.960)	0.026 (0.657)	-0.040 (0.039)**
Per capita alcohol consumption (gallons)	-0.001 (0.829)	0.0004 (0.928)	0.001 (0.697)
Population Density (per square mile-Log)	-0.007 (0.001)***	-0.008 (<0.001)***	-0.004 (<0.001)***
Constant	0.192 (0.219)	0.113 (0.533)	0.107 (0.106)
R-squared	0.37	0.32	0.47
Sample Size	2050	2050	2050

Source : Authors' calculations

**** p<0.01, ** p<0.05, * p<0.1*

As for life expectancy, several demographic factors are associated with the impact of homicide on lifespan inequality. States with a higher proportion of the Black population experience a significantly greater increase in lifespan inequality due to homicide. A one standard deviation (9 percentage point) higher proportion Black population is associated with a 0.473 standard deviation higher impact of homicide on lifespan inequality for the total population, a 0.831 standard deviation higher impact of homicide on lifespan inequality for males, and a 0.450 standard deviation higher impact of homicide on lifespan inequality for females. These results are further supported by the work of Light and Vachuska (2024), who demonstrated that increased homicide rates significantly contributed to widening Black-White disparities in life expectancy and lifespan inequality. Also, like life expectancy, the proportion of the population aged 25-34 is associated with a significantly greater impact of homicide on lifespan inequality. A one standard deviation (2 percentage point) higher proportion of the population aged 25-34 is associated with a 0.076 standard deviation higher impact of homicide on lifespan inequality for the total population, a 0.100 standard deviation higher impact of homicide on lifespan inequality for males, and a 0.215 standard deviation higher impact of homicide on lifespan inequality for females.

Like life expectancy, higher educational attainment is associated with lower impacts of homicide on lifespan inequality, but this is mainly statistically significant only for the percentage of high school graduates. One standard deviation (6 percentage point) higher proportion of high school graduates is associated with a 0.109 standard deviation lower impact of homicide on lifespan inequality for the total population, a 0.141 standard deviation lower impact of homicide on lifespan inequality for males, and a 0.148 standard deviation lower impact of homicide on lifespan inequality for females. In contrast, college education is only marginally statistically significant for females, and not significant for males or the total population.

A wider range of public spending categories is statistically associated with homicide-related lifespan inequality changes than was the case for life expectancy. Corrections expenditures are significantly associated with a larger impact of homicide on lifespan inequality. One standard deviation higher spending on corrections per capita is associated with a 0.097 standard deviation higher impact of homicide on lifespan inequality for the total population, a 0.155 standard deviation higher impact of homicide on lifespan inequality for males, and a 0.245 standard deviation higher impact of homicide on lifespan inequality for females. Judicial expenditure is also significantly associated with a larger impact of homicide on lifespan inequality. One standard deviation higher judicial spending per capita is associated with a 0.113 standard deviation higher impact of homicide on lifespan inequality for the total population, a 0.191 standard deviation higher impact of homicide on lifespan inequality for males, and a 0.124 standard deviation higher impact of homicide on lifespan inequality for females.

Unlike life expectancy, health, police, and welfare spending were all statistically significantly associated with the impact of homicide on lifespan inequality. One standard deviation higher health spending per capita is associated with a 0.034 standard deviation lower impact of homicide on lifespan inequality for the total population, and a 0.096 standard deviation lower impact of homicide on lifespan inequality for females but had no statistically significant association with the impact of homicide on lifespan inequality for males. One standard deviation higher police spending per capita is associated with a 0.040 standard deviation lower impact of homicide on lifespan inequality for the total population, and a 0.064 standard deviation lower impact of homicide on lifespan inequality for both males and females. One standard deviation higher public welfare spending per capita is associated with a 0.106 standard deviation higher impact of homicide on lifespan inequality for the total population, a 0.156 standard deviation higher impact of homicide on lifespan inequality for males, and a 0.086 standard deviation higher impact of homicide on lifespan inequality for females.

If there is no statistically significant effect on homicide's impact on life expectancy, but the effect on homicide's impact on lifespan inequality is statistically significant (as is the case for these three spending variables), then that means there must be some offsetting effects that keep the mean change in the age at death distribution the same (the impact on life expectancy is zero), but at the same time the impact of homicide is increasing lifespan inequality by less (if the effect is negative – health, police) or more (if the effect is positive – welfare).

Increased police and health spending may reduce homicides in the age groups that are most responsive to interventions, thereby narrowing the distribution of age at death. For example, initiatives in public health and law enforcement, such as focused deterrence strategies, substance abuse treatment, or community healthcare access, can shift the timing or profile of homicides without affecting the overall rate.

On the other hand, if a variable like welfare spending increases the impact of homicide on lifespan inequality without affecting life expectancy, this may reflect disparities in how different age groups benefit from such spending. States with higher welfare spending often have higher baseline poverty and social disadvantages. Although welfare programs like the

Earned Income Tax Credit and SNAP provide critical support, they may not directly address factors influencing the age distribution of homicide, such as access to mental health care, social services, or community support mechanisms.

Older adults are more likely to benefit from welfare-related healthcare support and stable income streams (e.g., Social Security, Medicaid), which can reduce stress and vulnerability to violence. Meanwhile, if homicide remains concentrated in younger populations not fully reached by these interventions, the overall variability in age at death can widen, increasing lifespan inequality.

Unlike life expectancy, the firearms policy variables are all statistically insignificant in their associations with the impact of homicide on lifespan inequality, except for a marginally significant negative effect of the No Stand Your Ground law for females. Finally, population density is associated with lower impacts of homicide on lifespan inequality. Specifically, one standard deviation higher population density is associated with a 0.109 standard deviation lower impact of homicide on lifespan inequality for the total population, a 0.141 standard deviation lower impact of homicide on lifespan inequality for males, and a 0.188 standard deviation lower impact of homicide on lifespan inequality for females.

3.4 Conclusion

This study investigated the impact of homicide on life expectancy and lifespan inequality across US states from 1968 to 2020, revealing both shared and distinct influences of socioeconomic, demographic, and policy-related factors. Regional disparities underscore the uneven impact of homicide across the US: Southern states consistently experienced the highest life expectancy losses and greatest increases in lifespan inequality due to homicide, while states in the Northeast showed comparatively lower impacts and even slight improvements in some states. The Midwest experienced some of the most concerning recent reversals, with rising lifespan inequality despite a historical trend of improvements. A clear gender difference was also apparent across all states, with impacts of homicide on male life expectancy and lifespan inequality being greater than for females.

According to our findings, demographic factors emerge as critical, with the proportion of high school graduates consistently associated with lower impacts of homicide on life expectancy and lifespan inequality. Racial disparities are also pronounced, with the proportion of the Black population significantly linked to larger effects on both life expectancy and lifespan inequality, likely reflecting systemic inequities in exposure to violence. This reinforces the understanding that homicides can exacerbate existing social inequalities, particularly in marginalized communities (Elo et al., 2019; Johnson et al., 2021). The age group 25–34 appeared to amplify homicide's effects more than the 15–24 age group, possibly reflecting vulnerability during prime working and reproductive years (Tillyer & Race, 2016; García & Aburto, 2019; Aburto & Beltrán-Sánchez, 2019).

Our results also show that structural or system-wide expenditures (e.g., corrections, judicial) are associated with homicide-related mortality across multiple age groups, affecting both life expectancy and lifespan inequality. Welfare spending, although providing support to many, may not reduce homicide among younger populations without additional targeted interventions. In light of these findings, policymakers could consider further evaluating interventions aimed at improving socioeconomic conditions, reducing exposure to violence, and closing racial and educational gaps. For instance, higher high-school graduation rates are associated with a lower homicide burden, suggesting the potential value of education-focused interventions that help keep young people in school and reduce the risk of later criminal involvement. Future research is needed to isolate the mechanisms through which different types of public expenditures influence homicide outcomes. This would ideally involve analysis that aims to identify the *causal* impact of public spending on homicide.

While this study provides valuable insights, several limitations must be acknowledged. First, the analysis focuses exclusively on homicide mortality, neglecting impacts on morbidity and quality of life, which are also critical components of health outcomes. Second, some important cultural and political factors may influence homicide rates but were not included due to data availability and reliability constraints. Third, exploring individual-level pathways and conducting micro-scale analyses (e.g., county-level, city-level or individual-level) could provide a more comprehensive picture of the drivers of homicide and its differential impacts on life expectancy and lifespan inequality. Fourth, international comparisons might yield further insights into the broader structural determinants of homicide-related mortality and inequality. Finally, the analysis does not provide causal evidence of the factors associated with life expectancy and lifespan inequality changes due to homicide. Addressing these gaps in future research would enhance our understanding of homicide's complex effects and contribute to the design of more evidence-based and equitable public health policies.

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Appendix

Table A1: Determinants of decrease in Life expectancy due to homicide: Fixed Vs Random Effect

Variable	Model 1 Contribution of Homicide to Life Expectancy Loss -Total Population		Model 2 Contribution of Homicide to Life Expectancy Loss - Male Population		Model 3 Contribution of Homicide to Life Expectancy Loss - Female Population	
	FE	RE	FE	RE	FE	RE
% of Black Population	1.951 (<0.001)***	1.090 (<0.001)***	2.699 (<0.001)***	1.642 (<0.001)***	0.252 (0.104)	0.326 (<0.001)***
% of White Population	1.053 (<0.001)***	0.259 (<0.001)***	1.486 (<0.001)***	0.425 (<0.001)***	0.294 (0.004)***	0.025 (0.314)
% of Age Group(15-24)	-0.209 (0.013)**	-0.240 (0.005)***	-0.342 (0.007)***	-0.373 (0.004)***	-0.076 (0.242)	-0.183 (0.005)***
% of Age Group(25-34)	0.553 (<0.001)***	0.749 (<0.001)***	0.670 (<0.001)***	0.941 (<0.001)***	0.399 (<0.001)***	0.526 (<0.001)***
% of High School Graduate	-0.343 (<0.001)***	-0.249 (<0.001)***	-0.524 (<0.001)***	-0.389 (<0.001)***	-0.132 (0.001)***	-0.111 (0.002)***
% of College Graduate	0.393 (<0.001)***	0.285 (<0.001)***	0.628 (<0.001)***	0.478 (<0.001)***	0.154 (0.001)***	0.011 (0.800)
Per Capita Corrections Expenditure (Log)	-0.038 (0.001)***	0.003 (0.819)	-0.051 (0.003)***	0.006 (0.732)	-0.005 (0.542)	0.031 (<0.001)***
Per Capita Education Expenditure (Log)	-0.033 (0.106)	-0.013 (0.538)	-0.027 (0.390)	-0.004 (0.898)	-0.046 (0.004)***	-0.020 (0.143)
Per Capita Judicial Expenditure (Log)	-0.009 (0.337)	-0.025 (0.007)***	-0.023 (0.107)	-0.043 (0.002)***	-0.001 (0.902)	-0.016 (0.012)**
Per Capita Health Expenditure (Log)	0.034 (<0.001)***	0.026 (0.001)***	0.052 (<0.001)***	0.042 (0.001)***	0.013 (0.032)**	0.005 (0.383)
Per Capita library Expenditure (Log)	0.010 (0.035)	0.016 (0.001)***	0.019 (0.001)***	0.026 (<0.001)***	0.003 (0.444)	0.00007 (0.984)
Per Capita Police expenditure (Log)	-0.011 (0.306)	-0.018 (0.109)	-0.029 (0.082)*	-0.036 (0.032)**	0.0006 (0.994)	-0.009 (0.249)

Per Capita Public Welfare Expenditure (Log)	0.089 (<0.001)***	0.062 (<0.001)***	0.159 (<0.001)***	0.119 (<0.001)***	0.036 ((<0.001)***	0.017 (0.039)**
Per Capita Unemployment allowances Expenditure (Log)	0.006 (0.293)	0.007 (0.270)	0.011 (0.235)	0.012 (0.204)	0.001 (0.852)	-0.002 (0.590)
Universal Background Checks Law	0.016 (0.003)***	0.012 (0.032)**	0.032 (<0.001)***	0.025 (0.002)***	0.001 (0.829)	-0.002 (0.625)
Permit to Purchase Law (Gun)	-0.019 (0.004)***	-0.007 (0.257)	-0.029 (0.003)***	-0.012 (0.207)	-0.003 (0.607)	0.003 (0.466)
No Stand Your Ground Law (Gun)	-0.003 (0.392)	-0.002 (0.523)	-0.005 (0.373)	-0.003 (0.578)	0.001 (0.66)	-0.001 (0.769)
Unemployment Rate (%)	-0.004 (<0.001)***	-0.005 (<0.001)***	-0.006 (<0.001)***	-0.007 (<0.001)***	-0.002 (0.004)***	-0.002 (<0.001)***
Real Per Capita Income (Log)	0.002 (0.938)	-0.056 (0.007)***	-0.022 (0.498)	-0.101 (0.001)***	0.006 (0.742)	-0.025 (0.080)*
Gini Coefficient	-0.059 (0.148)	-0.077 (0.061)	-0.045 (0.455)	-0.069 (0.258)	-0.058 (0.062)*	-0.081 (0.007)***
Per capita alcohol consumption (gallons)	0.005 (0.350)	0.025 (<0.001)***	0.002 (0.756)	0.032 (<0.001)***	0.013 (0.002)***	0.014 (<0.001)***
Population Density(per square mile-Log)	-0.099 (<0.001)***	-0.023 (<0.001)***	-0.140 (<0.001)***	-0.031 (<0.001)***	-0.065 (<0.001)***	-0.010 (<0.001)***
Constant	-0.487 (0.065)*	0.419 (0.035)**	-0.542 (0.172)	0.653 (0.030)**	0.083 (0.683)	0.363 (0.006)***
Heteroscedasticity test	0.000		0.000		0.000	
Serial correlation test	0.000		0.000		0.175	
R-squared	0.27	0.49	0.22	0.48	0.27	0.44
Sample Size	2050	2050	2050	2050	2050	2050

Source : Authors' calculations

**** p<.01, ** p<.05, * p<.1*

Table A2: Determinants of changes in lifespan inequality due to homicide: Fixed Vs Random Effect

Variable	Model 1 Contribution of Homicide to Lifespan Inequality -Total Population		Model 2 Contribution of Homicide to Lifespan Inequality - Male Population		Model 3 Contribution of Homicide to Lifespan Inequality - Female Population	
	FE	RE	FE	RE	FE	RE
% of Black Population	1.048 (<0.001)***	0.917 (<0.001)***	1.727 (<0.001)***	0.903 (<0.001)***	0.198 (0.006)***	0.188 (<0.001)***
% of White Population	0.618 (<0.001)***	0.487 (<0.001)***	0.946 (<0.001)***	0.257 (<0.001)***	0.224 (<0.001)***	0.037 (0.012)
% of Age Group(15-24)	-0.156 (0.001)***	-0.156 (0.001)***	-0.230 (0.002)***	-0.241 (<0.001)	-0.035 (0.246)	-0.067 (0.029)**
% of Age Group(25-34)	0.361 (<0.001)***	0.395 (<0.001)***	0.466 (<0.001)***	0.609 (<0.001)***	0.217 (<0.001)***	0.277 (<0.001)***
% of High School Graduate	-0.121 (<0.001)***	-0.101 (<0.001)***	-0.172 (<0.001)***	-0.108 (0.012)**	-0.052 (0.004)	-0.030 (0.082)*
% of College Graduate	0.155 (<0.001)***	0.138 (<0.001)***	0.231 (<0.001)***	0.162 (0.003)***	0.075 (0.001)	0.013 (0.547)
Per Capita Corrections Expenditure (Log)	-0.005 (0.436)	0.002 (0.772)	-0.012 (0.239)	0.016 (0.093)*	0.004 (0.302)	0.021 (<0.001)***
Per Capita Education Expenditure (Log)	-0.009 (0.428)	-0.006 (0.616)	-0.007 (0.720)	0.003 (0.861)	-0.011 (0.149)	-0.002 (0.786)
Per Capita Judicial Expenditure (Log)	-0.006 (0.256)	-0.009 (0.109)	-0.008 (0.309)	-0.020 (0.015)**	0.0002 (0.942)	-0.007 (0.029)
Per Capita Health Expenditure (Log)	0.015 (0.001)***	0.014 (0.003)***	0.024 (0.001)***	0.019 (0.008)***	0.002 (0.466)	-0.002 (0.603)
Per Capita library Expenditure (Log)	0.007 (0.014)**	0.008 (0.004)***	0.012 (0.003)***	0.017 (<0.001)***	0.001 (0.608)	0.001 (0.679)
Per Capita Police expenditure (Log)	-0.011 (0.085)*	-0.012 (0.051)*	-0.018 (0.067)*	-0.023 (0.017)**	0.001 (0.746)	-0.004 (0.349)
Per Capita Public Welfare Expenditure (Log)	0.052	0.046	0.082	0.067	0.015	0.006

	(<0.001)***	(<0.001)***	(<0.001)***	(<0.001)***	(0.001)***	(0.127)
Per Capita Unemployment allowances Expenditure (Log)	0.006 (0.059)*	0.007 (0.043))*	0.011 (0.038)**	0.011 (0.035)**	-0.001 (0.714)	-0.001 (0.524)
Universal Background Checks Law	0.007 (0.002)	0.006 (0.046)**	0.013 (0.009)***	0.009 (0.047)**	-0.001 (0.526)	-0.003 (0.101)
Permit to Purchase Law (Gun)	-0.007 (0.060)	-0.005 (0.175)	-0.012 (0.033)**	-0.005 (0.405)	-0.001 (0.526)	0.002 (0.353)
No Stand Your Ground Law (Gun)	0.003 (0.890)	0.001 (0.712)	-0.002 (0.609)	-0.001 (0.665)	0.001 (0.519)	0.0004 (0.766)
Unemployment Rate (%)	-0.003 (<0.001)***	-0.003 (<0.001)***	-0.004 (<0.001)***	-0.005 (<0.001)***	-0.001 (0.002)***	-0.001 (<0.001)***
Real Per Capita Income (Log)	-0.013 (0.283)	-0.023 (0.058)*	-0.028 (0.152)	-0.067 (<0.001)***	-0.004 (0.639)	-0.021 (0.002)***
Gini Coefficient	-0.035 (0.126)	-0.038 (0.099)*	-0.009 (0.808)	-0.012 (0.730)	-0.039 (0.007)***	-0.050 (<0.001)***
Per capita alcohol consumption (gallons)	-0.001 (0.807)	0.004 (0.209)	-0.007 (0.114)	0.008 (0.057)*	0.005 (0.004)***	0.008 (<0.001)***
Population Density(per square mile-Log)	-0.045 (<0.001)***	-0.029 (<0.001)***	-0.050 (<0.001)***	-0.012 (0.006)***	-0.030 (<0.001)***	-0.004 (<0.001)***
Constant	-0.270 (0.073)*	-0.135 (0.328)	-0.489 (0.036)**	0.326 (0.064)	-0.017 (0.860)	0.202 (0.002)***
Heteroscedasticity test	0.000		0.000		0.000	
Serial correlation test	0.000		0.000		0.0395	
R-squared	0.25	0.08	0.19	0.44	0.34	0.44
Sample Size	2050	2050	2050	2050	2050	2050

Source: Authors' calculations

**** p<.01, ** p<.05, * p<.1*

Table A3: Cross-sectional dependence test

	Life Expectancy			Lifespan Inequality		
	Model1	Model2	Model 3	Model 1	Model 2	Model 3
Pesaran's test of cross-sectional independence	27.145 (0.000)	25.866 (0.000)	10.038 (0.000)	23.839 (0.000)	24.948 (0.000)	8.214 (0.000)
Average absolute value of the off-diagonal elements	0.248	0.248	0.180	0.241	0.242	0.166

Source: Authors' calculations

Table A4: Second Generation Unit root test

Variable	CADF		CIPS	
	I(0)	I(1)	I(0)	I(1)
Loss of Life expectancy due to Homicide -Total Population	-1.909	-4.382 ***	-3.180 ***	-6.074 ***
Loss of Life expectancy -Male Population	-1.938	-4.297 ***	-3.496 ***	-6.082 ***
Loss of Life expectancy -Female Population	-2.720 ***	-4.897	-4.707 ***	-6.190 ***
Contribution of Homicide to Lifespan Inequality -Total Population	-1.932	-4.635 ***	-3.398 ***	-6.115 ***
Contribution of Homicide to Lifespan Inequality -Male	-1.986 *	-4.394	-3.624 ***	-6.129 ***
Contribution of Homicide to Lifespan Inequality -Female	-2.862 ***	-5.097 ***	-4.944 ***	-6.179 ***
% of Black Population	-2.009 ***	-2.121 ***	-1.824	-3.102 ***
% of White Population	-1.948 *	-2.292 ***	-1.721	-3.141***
% Age Group (15-24)	-2.224 ***	-2.355***	-2.473 ***	-2.556 ***
% Age Group (25-34)	-2.673***	-1.944 *	-2.567 ***	-2.403 ***
% of High School Graduate	-2.477 ***	-4.173***	-3.232 ***	-6.038 ***
% of College Graduate	-1.548	-3.617 ***	-1.821	-5.630 ***
Per Capita Corrections Expenditure (Log)	-2.467 ***	-3.832 ***	-2.661 ***	-5.872 ***
Per Capita Education Expenditure (Log)	-2.267 ***	-3.529 ***	-2.616 ***	-5.915 ***
Per Capita Judicial Expenditure (Log)	-2.188 ***	-3.942 ***	-2.582 ***	-5.801 ***
Per Capita Health Expenditure (Log)	-1.952*	-3.648***	-2.143 ***	-5.789 ***
Per Capita Library Expenditure(Log)	-1.747	-3.820 ***	-2.604 ***	-6.075***
Per Capita Police expenditure (Log)	-2.269 ***	-3.818 ***	-2.526 ***	-5.971***

Per Capita Public Welfare Expenditure (Log)	-1.872	-3.632 ***	-2.256 ***	-5.809 ***
Per Capita Unemployment allowances Expenditure (Log)	-1.996 ***	-3.723 ***	-2.253 ** *	-5.589 ***
Unemployment Rate (%)	-2.290 ***	-3.523 ***	-2.526 ***	-5.604 ***
Real Per Capita Income (Log)	-2.549 ***	-2.928 ***	-2.232 ***	-4.477 ***
Gini Coefficient	-2.521***	-2.914***	-2.489 ***	-4.866 ***
Per capita alcohol consumption (gallons)	-1.493	-3.645 ***	-1.938	-5.881 ***
Population Density (per square mile-Log)	-1.550	-2.193 ***	-1.969	-2.121***

Source: Authors' calculations

Chapter 4: A tale of three pandemics: Impacts on life expectancy and lifespan inequality

Abstract

This study aims to provide a comparative analysis of the impacts of three significant pandemics – the 1918-19 influenza pandemic, the HIV/AIDS epidemic, and the COVID-19 pandemic – on life expectancy and lifespan inequality. Using cause-eliminated life tables and the Theil Index, we examine changes in life expectancy and lifespan inequality globally. The findings reveal that each pandemic uniquely altered demographic patterns. The 1918 influenza pandemic caused the sharpest immediate reductions in life expectancy, particularly affecting young adults, and led to a significant rise in lifespan inequality. In contrast, the HIV/AIDS epidemic had a more gradual and enduring impact, disproportionately affecting young and middle-aged adults in its early stages and exacerbating health disparities, especially in regions with limited access to antiretroviral therapy. COVID-19 primarily impacted older populations, resulting in smaller reductions in life expectancy compared to the 1918 influenza but with a distinctive decrease in lifespan inequality due to concentrated mortality among older adults. Furthermore, gender-specific effects varied across the pandemics. While the 1918 influenza pandemic and COVID-19 showed relatively uniform impacts across genders, HIV/AIDS revealed pronounced disparities, with women experiencing greater reductions in life expectancy and heightened lifespan inequality. By examining the unique mortality patterns and impacts of these pandemics, this study provides valuable insights to policymakers, emphasizing the need for tailored public health strategies to address inequalities and improve resilience in future global health crises.

Keywords

Life Expectancy

Lifespan Inequality

1918 Influenza

HIV/AIDS

COVID-19

Pandemics

4.1 Introduction

Health crises, such as the recent COVID-19 pandemic (2020-2021), the ‘influenza pandemic’ (1918-1919) – also known as the “mother of all pandemics” (Taubenberger and Morens 2006) – and the HIV/AIDS pandemic (1990-), have caused extensive morbidity and mortality over the last 100 years . For instance, the influenza epidemic of 1918, which emerged immediately after World War I, is one of the deadliest pandemics in history, claiming an estimated 50 to 100 million lives worldwide (Johnson & Mueller, 2002). It had an unusual age distribution, with high mortality among young adults, which challenged existing understandings of infectious disease dynamics. This pandemic spread rapidly, affecting nearly every region of the world within a relatively short period. In contrast, the HIV/AIDS pandemic, which began in the early 1980s, unfolded differently. While HIV spread more gradually than the influenza virus, it had a deeply transformative and long-lasting impact and has caused over 40 million deaths worldwide (UNAIDS, 2020). Unlike the influenza pandemic, which had a rapid onset and short duration, HIV became a chronic global health crisis, disproportionately affecting sub-Saharan Africa and other marginalised populations (Moyo et al., 2023). It primarily reduced life expectancy in regions with inadequate healthcare infrastructure, exacerbating existing health disparities (Asghari et al., 2018; Marty et al., 2021; Tian et al., 2023). However, the advent of antiretroviral therapies (ART) in the mid-1990s helped to stabilize and even improve life expectancy among those living with HIV, though the virus remains a major public health issue in many parts of the world (Oguntibeju, 2012; Ghosh, 2023). The COVID-19 pandemic, which began in December 2019, has had profound and lasting effects on global health, surpassing any event experienced in the past half-century, including wars and natural disasters. The World Health Organization declared an end to the global coronavirus emergency in 2023, having recorded nearly 7 million deaths attributed to the virus (De Cock et al., 2021).

A growing body of literature highlights that pandemics can affect countries differently. For instance, Furceri et al., (2022) show that past pandemics have had a substantial impact on income inequality, and early evidence suggests that the distributional consequences of the COVID-19 pandemic could have been substantial (Wildman, 2021; Su et al., 2022; Tan et al., 2021; Demenech et al., 2020). Additionally, due to increases in mortality worldwide, pandemics directly and indirectly cause stagnation or declines in life expectancy. For example, life expectancy at birth decreased significantly during the influenza pandemic in 1918 (Grove and Hetzel, 1968; Noymer and Garenne, 2000; Sawchuk, 2009). Furthermore, the COVID-19 pandemic has had a profound impact on life expectancy, significantly altering demographic trends and exacerbating existing disparities across various racial, ethnic, and socioeconomic groups (Huang et al., 2023; Kuehn, 2022; Schöley et al., 2022; Aburto et al., 2021). In the context of HIV/AIDS, research by Aburto et al., (2021) highlighted that life expectancy reductions in the US differed between racial groups during the period from 1980 to 2000, with more significant impacts on black individuals compared to white individuals. Additionally, the HIV/AIDS pandemic exacerbated lifespan inequality during this time. Further analysis by Dorling et al. (2005) revealed that the global difference in life expectancy was significantly larger than the differences within the UK during the early 2000s. This gap would have widened even further if the effects of AIDS were considered. HIV/AIDS plays a major role in exacerbating the differences in life expectancy between regions such as Africa and North America (Dorling et al., 2005).

In this context, our study focuses on variation in age at death or lifespan inequality, offering a comparative analysis of the three pandemics in a global context. While examining life expectancy is important, we argue that a more comprehensive understanding arises from exploring lifespan inequality, which provides deeper insights into the full distribution of the impacts of pandemics on the age-at-death distribution, because lifespan inequality, like life expectancy, serves as a critical measure of mortality patterns and population health. Lifespan inequality captures the variation in when individuals die, which may reflect broader social and health inequalities. Moreover, understanding lifespan inequality is essential at both the individual (micro) and population (macro) levels, as it reveals disparities in health outcomes and mortality risks (Wijesinghe et al, 2024).

At the individual level, lifespan variation recognises the unpredictability of when death might occur, emphasizing personal risk. This uncertainty can have profound psychological and economic consequences. Edwards (2013) suggests that because people are generally risk averse, they are willing to trade potential additional years of life for greater certainty regarding their lifespan. When lifespan inequality diverges across socioeconomic groups, it highlights an often-overlooked dimension of inequality: those from more privileged backgrounds are able to plan their lives more effectively, while individuals from disadvantaged groups face heightened unpredictability about their survival. This uncertainty influences key life decisions, such as education, employment, and retirement planning (Brown et al, 2012). For individuals with greater uncertainty, planning for the future becomes a more complex and stressful process.

At the population level, lifespan inequality reveals the overall heterogeneity in health within a society. A high degree of inequality suggests that different segments of the population are experiencing very different health outcomes. This information is crucial for designing effective public policies, including healthcare provision, insurance and pension systems, and equitable social safety nets. Rising lifespan inequality among disadvantaged groups indicates that members of these groups are leading increasingly diverse life courses, reflecting deeper social inequalities. For example, growing inequality in lifespan can parallel increasing inequality in other areas, such as access to education, employment, and family life (Brown et al, 2012).

In the context of pandemics, lifespan inequality tends to magnify existing health inequalities, with disadvantaged populations experiencing higher mortality rates and greater vulnerability to early and midlife mortality (McGowan and Bambra,2022). Therefore, monitoring lifespan inequality can serve as an early warning system for detecting adverse mortality trends, particularly in the aftermath of global health crises. However, the discussion of lifespan inequality in the context of health crises has received limited attention from scholars. For instance, Yadav and Yadav (2023) and Aburto et al. (2021) examined the effects of COVID-19 on life expectancy and lifespan inequality in India and in England and Wales, respectively. Additionally, Aburto et al. (2021) discussed Black-White disparities in life expectancy and lifespan inequality in the US due to HIV/AIDS, highlighting the ongoing impact of health crises. Expanding upon this limited base, the current study aims to conduct a comparative analysis of the effects of the 1918 influenza, HIV/AIDS, and COVID-19 on life expectancy and lifespan inequality. By analyzing the disparate effects of pandemics on lifespan inequality in particular, we attempt to fill a critical gap in the understanding of public health crises. These three health crises highlight the persistent obstacles encountered by global health systems and the significant disparities that exist within and between countries. Consequently, this study makes a significant contribution to the historical documentation of these events and offers invaluable insights to policymakers and public health officials. By doing so, it aspires to inform strategies that could alleviate the adverse impacts of future pandemics on lifespan inequality.

The remainder of the paper is organized as follows. Section 2 describes the data and provides a brief explanation of the methods. Section 3 presents the results and discussion. The final section concludes.

4.2 Data and Methods

We utilized various sources to obtain life tables and cause-of-death data covering the total population, males and females. The first part, focusing on the 1918-1919 influenza pandemic, primarily draws on data from the Human Mortality Database (HMD), which provides coverage for 11 countries during those years (Appendix, Table A1). Additionally, the number of deaths attributed to the influenza was gathered from different statistical yearbooks of the respective countries. Influenza pandemic mortality data were reported in irregular age groups across different countries, necessitating harmonization for consistency. Using a Penalized Composite Link Model (PCLM), we estimated death counts for each year of age from 0 to 110 based on the grouped data, ensuring robust and comparable age-specific mortality trends critical for demographic analyses (Rizzi et al., 2019, Aburto et al., 2021). The PCLM was independently applied to each combination of country, sex, and year.

The HIV/AIDS data covers 200 countries from 1990 to 2019 (Appendix, Table A1), with death data obtained from the Global Burden of Disease Study (GBD). GBD is the most comprehensive observational epidemiological study globally, offering detailed data on mortality and morbidity from major diseases, injuries, and risk factors at global, regional, and national levels from 1990 to the present (Global Burden of Disease Study, 2021).

COVID-19 death data for 2020 and 2021 were obtained from COVerAGE-DB, a global demographic database tracking COVID-19 cases, deaths, tests, and vaccines (Riffe et al., 2021). The sample includes data from 45 countries in 2020 (see Appendix, Table A1). In both years, the dataset spans at least until December 1st, ensuring that almost the full impact of the pandemic during 2020 and 2021 is likely captured. For both analyses of HIV/AIDS and COVID-19, population data and country life tables were sourced from the United Nations' World Population Prospects 2024 (United Nations, Department of Economic and Social Affairs, Population Division, 2024).

Demographic and statistical techniques

This study employs the life table and cause-eliminated life table methods to estimate changes in life expectancy and lifespan inequality caused by the 1918 influenza, HIV/AIDS, and COVID-19. The first step in this approach is calculating the probabilities of survival ($_np_x$) from the all-cause abridged life tables. The formula for this calculation is as follows:

$$\boldsymbol{{}_nP_x = 1 - {}_nq_x} \tag{1}$$

where x is the exact age, n is the number of years in the age interval, and ($_np_x$) is the probability of dying between the beginning of an age interval and before reaching the end of that age interval. Then, the probability of death, eliminating the i_{th} cause ($_nq_{x1}^{(-i)}$) was estimated by:

$$\boldsymbol{{}_nq_{x_1}^{(-i)} = 1 - {}_np_x\left(\frac{{}_nD_x - {}_nD_x i}{{}_nD_x}\right)} \tag{2}$$

Where $_nD_x$ is the number of deaths in the age interval x to $x + n$ for all causes, and $_nD_x^i$ is the number of deaths in the age interval x to $x + n$ attributable to the i_{th} cause of death.

Next, the number of person-years lived ${}_{n}L_{x1}^{(-i)}$ in the age interval x to $x + n$ was estimated for ages 0, 1, 5, 10,…,100 using the formula:

$$ {}_{n}\boldsymbol{L}_{\boldsymbol{x}_1}^{(-\boldsymbol{i})} = (\boldsymbol{n} - {}_{n}\boldsymbol{f}_{\boldsymbol{x}}).\, \boldsymbol{l}_{\boldsymbol{x}}^{(-\boldsymbol{i})} + {}_{n}\boldsymbol{l}_{\boldsymbol{x}}..\, \boldsymbol{l}_{\boldsymbol{x}+\boldsymbol{n}}^{(-\boldsymbol{i})} \tag{3}$$

where n=1 for x = 0, n= 4 for x = 1, and n = 5 for x = 5,10 ..., 100, and ${}_{n}l_x$ the number of individuals from the original life table who survive to the beginning of each age interval, $l_x^{(-i)}$ denotes the number of survivors from the life table after eliminating deaths due to the i_{th} cause (influenza, HIV/AIDS, or COVID-19), L_x is the number of person-years lived within a specific age interval x from the original life table, and ${}_{n}f_x$ represents the force of mortality (probability of death) for the age interval and is estimated from the all-cause life table as follows:

$$ {}_{n}\boldsymbol{f}_{\boldsymbol{x}} = \frac{\boldsymbol{n}.\ {}_{n}\boldsymbol{l}_{\boldsymbol{x}} - {}_{n}\boldsymbol{L}_{\boldsymbol{x}}}{\boldsymbol{l}_{\boldsymbol{x}} - \boldsymbol{l}_{\boldsymbol{x}+\boldsymbol{n}}} \tag{4}$$

The last step is to calculate the number of person-years lived after the exact age x ($T_x^{(-i)}$) by:

$$ \boldsymbol{T}_{\boldsymbol{x}}^{(-\boldsymbol{i})} = \boldsymbol{L}_{\boldsymbol{x}}^{(-\boldsymbol{i})} + \boldsymbol{L}_{\boldsymbol{x}+\mathbf{1}}^{(-\boldsymbol{i})} + \cdots . + \boldsymbol{L}_{\mathbf{110+}}^{(-\boldsymbol{i})} \tag{5}$$

Finally, the cause-eliminated life expectancy ($e_x^{(-i)}$) is calculated as follows:

$$ \boldsymbol{e}_{\boldsymbol{x}}^{(-\boldsymbol{i})} = \frac{\boldsymbol{T}_{\boldsymbol{x}}^{(-\boldsymbol{i})}}{\boldsymbol{l}_{\boldsymbol{x}}^{(-\boldsymbol{i})}} \tag{6}$$

Subsequently, the contribution of a disease (in this case, the 1918 Influenza pandemic, HIV/AIDS, or COVID-19) to the change in life expectancy for a particular year can be quantified by calculating the difference between the cause-eliminated life expectancy ($e_x^{(-i)}$) and the observed life expectancy e_x in that same year. This difference provides a clear measure of the disease's impact on life expectancy by isolating its effect from other causes of death.

Lifespan inequality measurement – Theil index

Several studies, including Kannisto (2000), Shkolnikov et al. (2003), Vaupel et al. (2011), Wilmoth and Horiuchi (1999), and van Raalte and Caswell (2013), have explored indicators of lifespan inequality, highlighting strong associations among different metrics. In this study, we choose the Theil Index to measure lifespan inequality, as it is more responsive to variations across the full age-at-death distribution. Unlike the Gini index, which emphasises central tendencies, the Theil index's sensitivity to variations across the full age-at-death distribution provides a nuanced view of lifespan inequality, particularly in the context of pandemics characterized by age-specific mortality patterns. We calculate lifespan inequality for the total population and separately for males and females. The Theil index for lifespan inequality, which is denoted as T_a, can be calculated as follows:

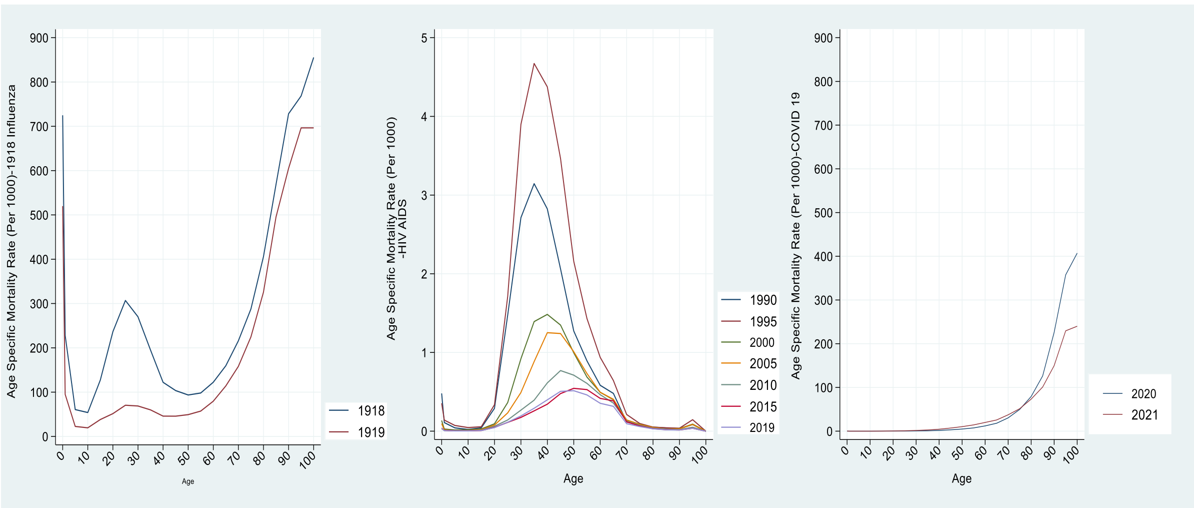
$$\boldsymbol{T_a = \frac{1}{l_a} \sum_{x=a}^{\omega} d_x \left(\frac{\alpha_x}{\mu_a}\right) log \left(\frac{\alpha_x}{\mu_a}\right)} \tag{7}$$

where a and ω are the youngest and oldest age intervals taken from a given life table, l_x is the radix of the population μ_a is the average age at death of the population, and d_x and α_x are the life table number of deaths and the average age at death in the age interval x to $x+5$, respectively.

4.3 Results and Discussion

To illustrate the differences in mortality patterns among those three pandemics, we first use the age-specific mortality distributions in the USA as an example. Figure 4.1 shows the age-specific 1918-19 influenza, HIV/AIDS, and COVID-19 mortality distribution (per 1000 population). Due to HIV/AIDS mortality rates being much lower overall, a different y-axis scale is used in the middle panel to improve visibility.

Figure 4.1: Age-Specific Mortality Distribution in 1918 Influenza, HIV/AIDS and COVID-19



Source: Authors' calculations

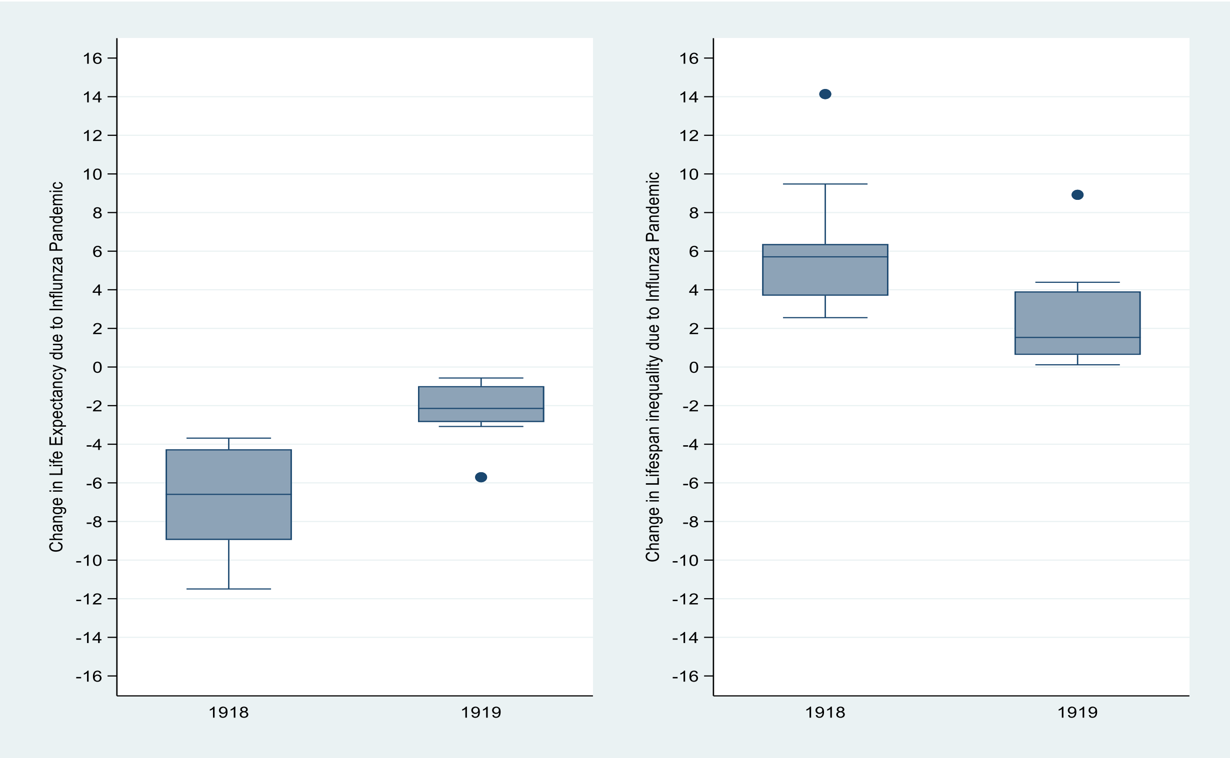
According to Figure 4.1, the 1918-1919 influenza pandemic displays a unique "W-shaped" curve, with high mortality rates among infants, young adults (ages 20-40), and the elderly, especially in 1918. This contrasts sharply with HIV/AIDS, which shows a peak in mortality among young and middle-aged adults (ages 30-50), with significantly lower overall rates and minimal impact on children and the elderly. In comparison, COVID-19 mortality follows an exponential pattern, with very low rates in younger populations but a steep rise among older adults, particularly those aged 60 and above, with the highest rates in the elderly (ages 80+).

Unlike influenza and HIV/AIDS, COVID-19 mortality is concentrated in older age groups, though the rates were slightly lower in 2021 compared to 2020. These differences highlight how each disease disproportionately affected different segments of the population, with influenza severely impacting the young and elderly, HIV/AIDS affecting younger and middle-aged adults, and COVID-19 predominantly impacting the elderly.

Impacts of Pandemics on Life Expectancy and Lifespan Inequality

Figure 4.2 illustrates the changes in life expectancy and lifespan inequality due to the 1918 influenza pandemic in the years 1918 and 1919, based on data from 11 countries. This was calculated by comparing life expectancy and lifespan inequality under two scenarios: one including all causes of death, and the other excluding deaths specifically attributed to the 1918 influenza pandemic, separately for each country in the sample (see Appendix, Tables A2 and A3). Each boxplot shows the distribution of the change in life expectancy (or lifespan inequality) across all countries in the sample.

Figure 4.2: Influenza Pandemic 1918 impacts on life expectancy and lifespan inequality



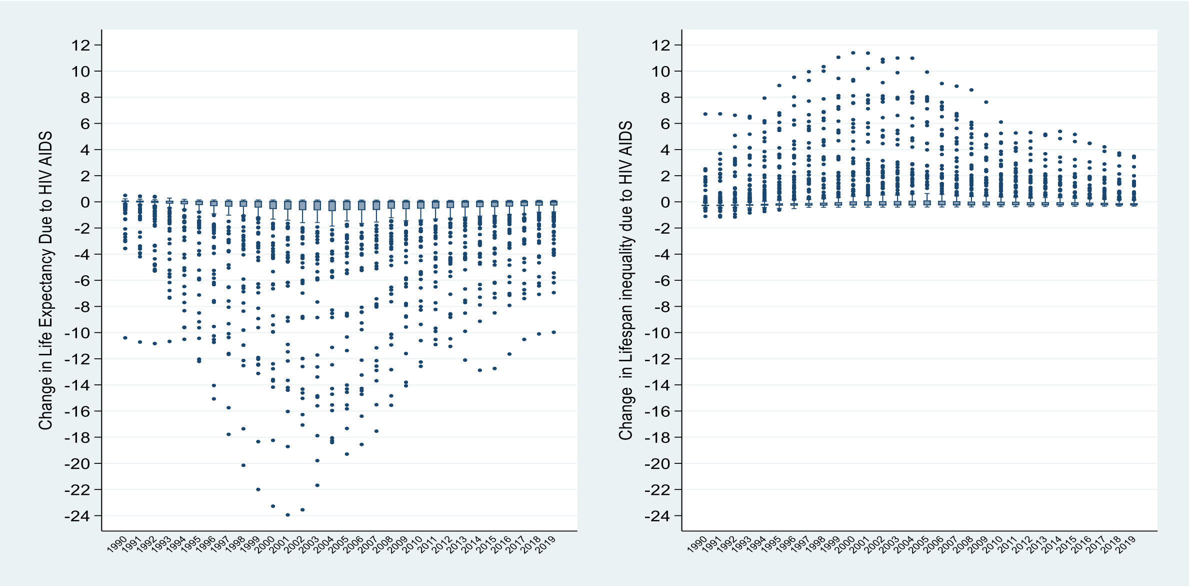
Source: Authors' calculations

The pandemic caused a significant drop in life expectancy and a sharp increase in lifespan inequality. In 1918, the mean decrease in life expectancy was 6.79 years. This suggests a severe and consistent impact across countries, with some variation in extreme cases. For instance, the US appears as an outlier, with a much larger drop of 11.49 years placing it well outside the interquartile range for that year and experiencing a notably different impact on life expectancy and lifespan inequality. Despite this variation, the relatively low standard deviation and moderate interquartile range (see Appendix, Table A6) suggest that the reduction in life expectancy was broadly similar across countries. In 1919, the impact on life expectancy was much less, with a mean decrease of 2.20 years. Although the US experienced a drop of 5.71 years, this value does not stand out to the same degree as an outlier compared to 1918. Comparing the distributions in 1918 and 1919, a *t*-test confirms that the difference in mean impact of the pandemic was smaller in 1919 than in 1918 ($p<0.001$).

The 1918 influenza pandemic's distinctive age-dependent mortality pattern, characterized by high risk among young adults (20–34 years) and comparatively lower risk for infants and those aged over 35 (van Wijhe et al., 2018), contributed to a marked increase in lifespan inequality. Erkoreka's (2010) study also underscores this heightened vulnerability of young adults during the pandemic across Europe, including Italy and Spain. In 1919, lifespan inequality experienced a lower impact, with a mean increase of 2.62, with a slightly higher interquartile range of 3.28 (see Appendix, Table A6). Again, the difference between the two years was statistically significant ($p=0.012$). This suggests a major shift in the distribution of ages at death during the peak year of the pandemic, followed by some recovery in inequality in the subsequent year. A Kolmogorov-Smirnov test reveals that the lifespan inequality distribution in 1919 differed significantly from that of the peak pandemic year of 1918,, likely reflecting a gradual return of age-at-death patterns toward typical levels ($p=0.023$).

Figure 4.3 illustrates the impact of the HIV/AIDS pandemic on life expectancy and lifespan inequality for each year from 1990 to 2019, based on data from 200 countries. This was calculated by comparing life expectancy and lifespan inequality under two scenarios: one including all causes of death, and the other excluding deaths specifically attributed to HIV/AIDS, separately for each country in the sample (the underlying data can be provided upon request).

Figure 4.3: HIV AIDS impacts on life expectancy and lifespan inequality



Source: Authors' calculations

Each boxplot in Figure 4.3 shows the distribution of the change in life expectancy (or lifespan inequality) across all countries in the sample. In 1990, the mean decrease in life expectancy due to HIV/AIDS was approximately 0.16 years for the total population, with a median of around 0.07. The high standard deviation and interquartile range (IQR) highlight the significant variation in life expectancy reductions, reflecting differences in epidemic intensity across countries (see Appendix, Table A7). The substantial number of extreme outliers represent countries, particularly in Sub-Saharan Africa, with notably higher mortality rates among young adults.

By 2008, partial recovery in life expectancy is observed, with the mean life expectancy loss due to HIV/AIDS reducing to 0.94 years. The narrower box plot for life expectancy and narrower range of outliers show decreasing variability in mortality distributions due to HIV/AIDS. The reduction in standard deviation and IQR (see Appendix, Table A7) reflects a shift towards a more uniform experience across countries. In 2018, life expectancy loss due to HIV/AIDS had further declined to approximately 0.48 years.

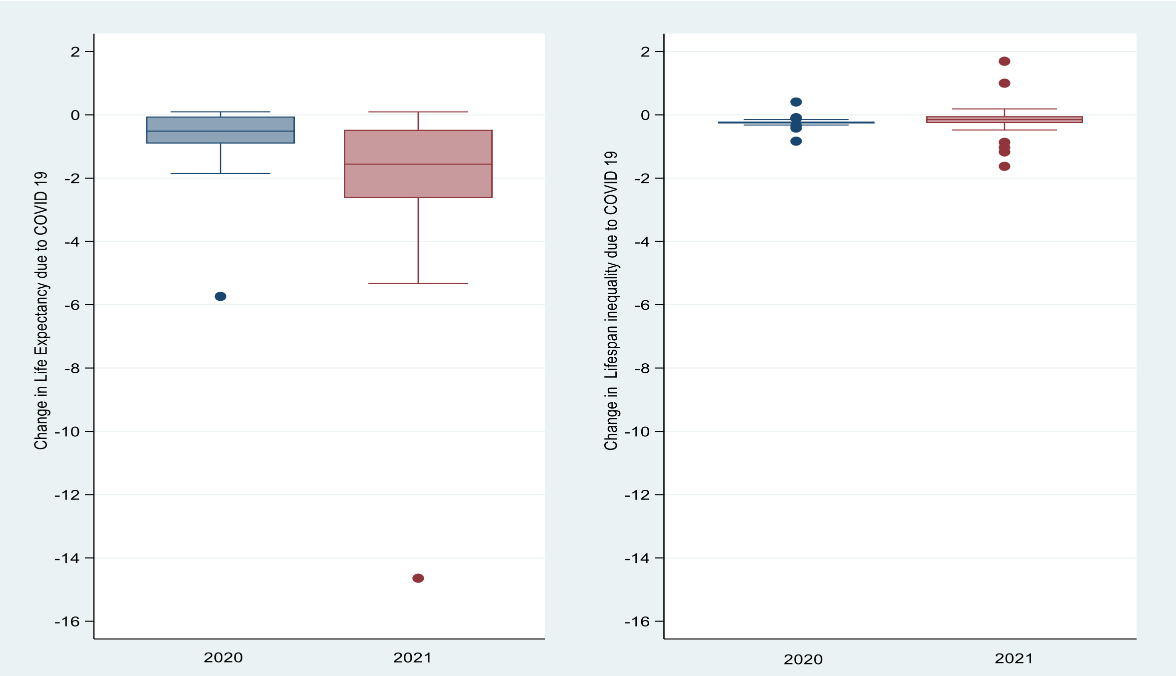
In 1990, the increase in lifespan inequality due to HIV/AIDS was significantly elevated, with a mean of 0.13 and a median of 0.27. By 1999, the increase in lifespan inequality due to HIV/AIDS had increased to a mean of 0.38 and a median 0.24. However, starting in the mid-2000s, there is a noticeable decline in the impact of HIV/AIDS on life expectancy and lifespan inequality. This demonstrates the beneficial effects of enhanced prevention efforts and greater access to antiretroviral therapy (ART). For example, in sub-Saharan Africa, ART has played a transformative role in decreasing HIV-related mortality and morbidity (Burger et al., 2022).

According to their findings, free ART contributed to a 27% reduction in annual mortality and a 36% decrease in poor health reports among black Africans aged 25-49 in South Africa. Globally, ART scale-up averted an estimated 4.2 million deaths in low- and middle-income countries from 2002 to 2012 (Ford et al., 2013), and studies report that HIV-related mortality rates dropped by over 58% across multiple locations following ART introduction (Reniers et al., 2014).

However, despite the increased availability of ART, there remains substantial variation in the impact of HIV/AIDS on life expectancy and lifespan inequality due to differing levels of treatment access, healthcare resources, and risk factors (Asghari et al., 2018; Marty et al., 2021; Tian et al., 2023). This persistent variability is especially evident in high-prevalence regions such as Sub-Saharan Africa, South and Southeast Asia, and the Caribbean, with countries like Botswana, Eswatini, Kenya, South Africa, Zambia, Zimbabwe, Mozambique, Malawi, and Namibia frequently appearing as outliers (Figure 3). By 2018, the impacts of HIV/AIDS on life expectancy and lifespan inequality are noticeably less than in 1990, as demonstrated by the box plots in Figure 4.3. This visual observation is further supported by the results of a Kolmogorov-Smirnov test, which reveals a significant difference in the distributions of lifespan inequality between 1990 and 2018 ($p<0.001$).

Figure 4.4 depicts the effects of the COVID-19 pandemic on life expectancy and lifespan inequality for 2020 and 2021, based on data from 45 countries. This was calculated by comparing life expectancy and lifespan inequality under two scenarios: one including all causes of death, and the other excluding deaths specifically attributed to COVID-19, separately for each country in the sample (see Appendix, Table A4 and A5). Each boxplot shows the distribution of the change in life expectancy (or lifespan inequality) across all countries in the sample.

Figure 4.4: COVID-19 impacts on life expectancy and lifespan inequality



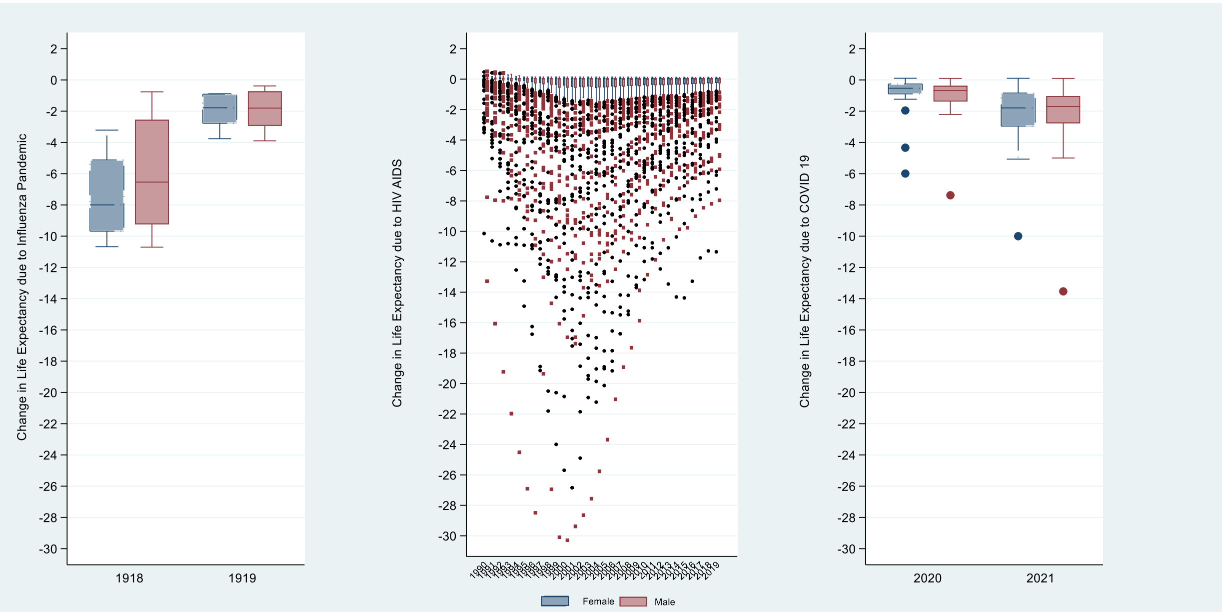
Source: Authors' calculations

In the first year of the COVID-19 pandemic (2020), the mean decrease in life expectancy for the total population was 0.65 years, with a median of 0.51. The standard deviation of 0.92 and interquartile range (IQR) of 0.85 indicate notable variability across countries. The box plot in Figure 4 highlights the substantial spread of life expectancy changes, indicating that different countries faced distinct pandemic-related challenges. In 2021, life expectancy loss increased sharply, with the mean reduction reaching 1.95 years with a median of 1.56. The standard deviation rose to 2.37, and the IQR expanded to 2.15, underscoring even greater disparities as some countries continued to struggle with COVID-19's impact. Some nations, such as South Korea, New Zealand, and Thailand, experienced relatively less impact due to strong pandemic responses, including effective leadership, communication, community engagement, and robust public health infrastructure (Chen & Assefa, 2021). In contrast, countries like the US, Italy, and Brazil, which faced challenges in these areas, experienced more significant mortality increases (Chen & Assefa, 2021). A Kolmogorov-Smirnov test confirms a significant difference in the distributions of the impact of COVID-19 on life expectancy between 2020 and 2021 ($p<0.001$). An outlier in the life expectancy box plot for both years is Peru which, by 2022, had around 6,500 COVID-19 deaths per million people, the highest rate worldwide (World Bank, 2023). Despite immediate measures such as lockdowns, social distancing, and business closures, Peru's underfunded healthcare system and lack of essential resources including ICU capacity contributed to its high mortality rate (Olivera, 2021). Historical underinvestment in public health in Peru further compounded these challenges (ECLAC, 2019).

Turning to the impact on lifespan inequality, the mean change in lifespan inequality in 2020 was a decrease of 0.24, with a median decrease of 0.25. Thus, unlike the other two pandemics, lifespan inequality did not increase substantially, likely due to the more uniform impact of COVID-19 on older age groups' mortality. By 2021, the mean change in lifespan inequality adjusted slightly to -0.16, with a median close to -0.15 (see Appendix, Table A8). The box plot for 2021 shows that while the overall change in lifespan inequality remained modest, some countries experienced more pronounced disparities in age-at-death patterns. For example, in Belgium (an outlier in Figure 4), the majority of deaths occurred among those aged 64 and older, with nearly half of deaths concentrated among those aged 84 and above (Peeters et al., 2021). Similarly, Brazil recorded the highest death rate among those over 60 (Azevedo e Silva et al., 2021). Comparing the distributions of lifespan inequality change due to COVID-19 between 2020 and 2021, a Kolmogorov-Smirnov test confirms a significant distributional change between 2020 and 2021 (p=0.001).

Figure 4.5 illustrates the impacts of all three pandemics on life expectancy changes separately by gender, showing how each event led to life expectancy reductions with varying severity between males and females.

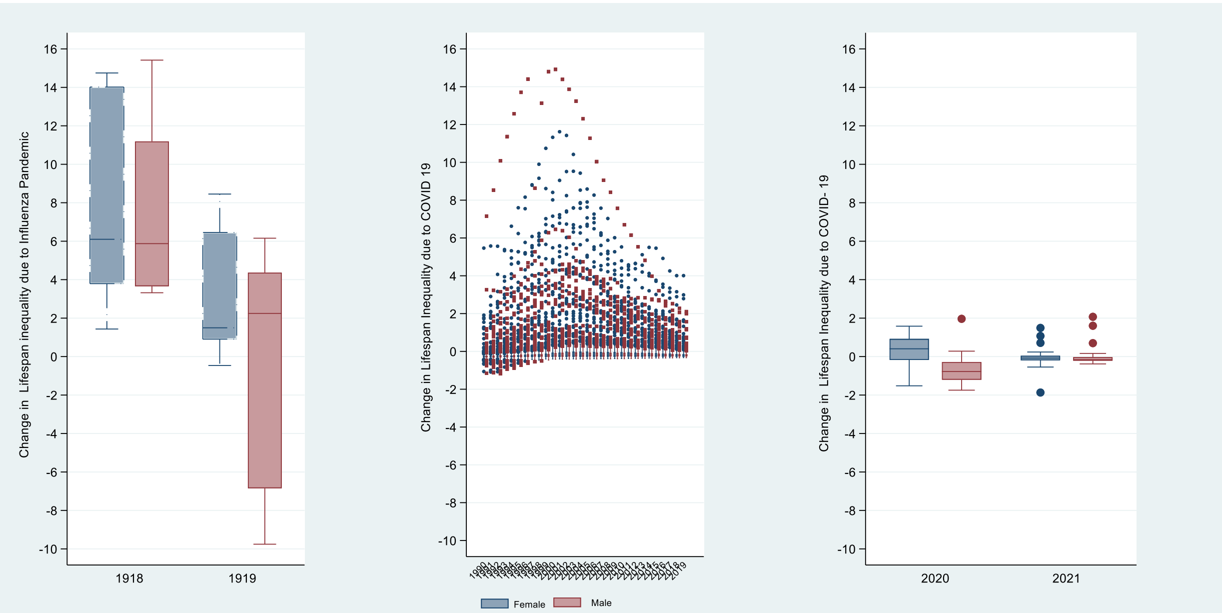
Figure 4.5: Pandemic impacts on life expectancy, by gender



Source: Authors' calculations

When comparing the impacts of the influenza pandemic, HIV and COVID-19, on life expectancy across genders, females experienced a mean life expectancy loss of 4.75 years compared to 4.01 years for males in the influenza pandemic in 1918. Although the female mean is slightly higher, a *t*-test (p = 0.5801) and Kolmogorov-Smirnov test (p = 0.617) show that these differences are not statistically significant. Our findings are consistent with empirical studies (e.g., Sawchuk, 2009; Paskoff & Sattenspiel, 2019) that found no significant differences in mortality based on sex during the 1918 influenza pandemic. In contrast, research from the US highlights a notable impact, showing that women lost much of their mortality advantage over men, a trend that persisted until the 1930s (Noymer & Garenne, 2000). In COVID-19, the mean loss of life expectancy was 1.48 years for females and 1.61 years for males. This similarity is confirmed by the *t*-test (p=0.365) and Kolmogorov-Smirnov test (p=0.318), indicating no significant gender-based differences in either the average loss or the overall distribution. Although some countries, such as Peru, Brazil, and Israel, appeared as outliers regarding female life expectancy loss in 2020, by 2021, only Peru remained an outlier. For males, Peru stood out as an outlier in both years. Considering HIV/AIDS, the mean life expectancy loss for females was -0.84 years, compared to -0.66 years for males. Both the *t*-test (p=0.001) and the Kolmogorov-Smirnov test (p<0.001) highlight significant differences in the averages and distribution, indicating distinct gender-specific patterns. These results are consistent with global epidemiological evidence showing that women bear a disproportionately higher burden of HIV in terms of infection rates, mortality, and broader health impacts (Wang et al., 2016; UNAIDS, 2017; Girum et al., 2018).

Figure 4.6: Pandemic impacts on lifespan inequality, by gender



Source: Authors' calculations

A *t*-test (p=0.438) and Kolmogorov-Smirnov test (p = 0.905) indicate no statistically significant differences in mean values or distribution shapes, suggesting that lifespan inequality was not substantially different between genders in the case of the 1918 influenza. In contrast, COVID-19 exhibits significant gender disparities, with males showing a mean lifespan inequality decrease of 0.34 years compared to an *increase* of 0.13 years for females. A *t*-test ($p = 0.0002$) and KS test ($p < 0.0001$) confirm statistically significant differences in both the mean and distribution between the genders. The results of our analysis align with existing empirical studies on COVID-19 mortality. According to Mamlook et al. (2020) and Hu et al. (2021), males have been more susceptible to severe disease and death from COVID-19 than females. This is further supported by Yanez et al. (2020), who found that mortality rates were 77% higher in men than in women, especially among older adults. HIV shows the most striking gender disparity, with females experiencing a mean lifespan inequality change of 0.14 years compared to 0.02 years for males. A *t*-test ($p < 0.0001$) and Kolmogorov-Smirnov test ($p < 0.0001$) reveal highly statistically significant differences in both magnitude and distribution, indicating distinct gender-specific patterns of lifespan inequality in the case of HIV. These findings align with broader epidemiological evidence showing that women, particularly in younger age groups, bear a disproportionately high burden of HIV. Of the 1 million AIDS-related deaths in 2017, women accounted for a larger share (UNAIDS, 2017). In Ethiopia specifically, 57% of AIDS-related deaths were among females (Ethiopian Public Health Institute, 2017). Moreover, AIDS-related illnesses remain the leading cause of death among women of reproductive age (15–49 years) globally (UNAIDS, 2017) and the second leading cause of death for young women aged 15–24 years in Africa (Wang et al., 2016).

4.4 Conclusion

This study examined the impact of three major pandemics: the 1918 influenza pandemic, the HIV/AIDS epidemic, and the COVID-19 pandemic, on life expectancy and lifespan inequality. By utilizing standard and cause-eliminated life tables, we quantified the changes in life expectancy associated with each pandemic, capturing changes in life expectancy and lifespan variability due to the unique mortality patterns of each pandemic.

We found that the 1918 influenza pandemic, HIV/AIDS epidemic, and COVID-19 pandemic all caused reductions in life expectancy, but their impacts differed in magnitude and dynamics over time. The 1918 influenza pandemic led to the most significant and immediate reductions, with life expectancy dropping sharply during its peak. COVID-19 also caused substantial reductions, concentrated among older populations, with losses increasing in 2021 compared to 2020. In contrast, the HIV/AIDS epidemic, though spanning decades, had a much smaller impact on life expectancy, with reductions peaking in the early 2000s. Notably, the HIV/AIDS epidemic revealed significant gender disparities, with women experiencing more pronounced reductions in life expectancy than men. By contrast, the impacts of the 1918 influenza and COVID-19 pandemics were more uniform across genders.

We also found that lifespan inequality showed divergent patterns across the three pandemics. Both the 1918 influenza pandemic and HIV/AIDS epidemic increased lifespan inequality significantly, but through different mechanisms. The 1918 influenza pandemic caused a sharp rise in inequality due to high mortality among younger adults, while HIV/AIDS, concentrated among young and middle-aged adults in its early stages, led to a more gradual increase over time. Conversely, the COVID-19 pandemic uniquely decreased lifespan inequality on average, as its mortality concentration among older adults smoothed age-at-death distributions. Our analysis highlights notable gender disparities in lifespan inequality across the three pandemics. While the 1918 influenza showed no significant gender differences in lifespan inequality, COVID-19 and HIV/AIDS both exhibit pronounced disparities. COVID-19 disproportionately affected males, while HIV/AIDS had a greater impact on females.

These findings provide important insights for future pandemics. The demographic age group most affected will play a critical role in determining the impacts on life expectancy and lifespan inequality. Pandemics that disproportionately affect younger populations are likely to cause sharp reductions in life expectancy and significant increases in lifespan inequality, as seen during the 1918 influenza pandemic. Conversely, pandemics that primarily affect older populations, such as COVID-19, may result in smaller reductions in life expectancy and potential decreases in lifespan inequality, as mortality is concentrated among those already near the end of the life course.

Our findings highlight the need for tailored, evidence-based policy responses. Policies for future pandemics must prioritize demographic-specific interventions. For pandemics like the 1918 influenza, which heavily affected younger adults, strategies should focus on vaccination, health education, and rapid deployment of medical resources to protect this demographic group. In contrast, pandemics such as COVID-19, which disproportionately impact older populations, demand robust investments in geriatric healthcare, long-term care facilities, and preventive measures like vaccines designed for older age groups. The findings also emphasize the critical role of addressing gender disparities in healthcare during pandemics. The pronounced impacts of the HIV/AIDS epidemic on women highlight the need for gender-sensitive healthcare programs. Finally, preparedness strategies should incorporate lessons from these historical pandemics. Enhanced surveillance systems, demographic-specific public health responses, and continuous monitoring of health inequalities trends can guide future interventions.

Even though our study offers valuable insights into three different pandemics, there are some limitations. A primary limitation of this study is the lack of reliable, age- and sex-specific mortality data for a wider selection of countries, particularly for the 1918 influenza pandemic. Incomplete or inconsistent records from this period hinder the precision of mortality estimates and limit the ability to fully assess the age and gender impacts. For HIV/AIDS and COVID-19, more detailed data are available, but regional discrepancies in data collection quality and completeness may still present challenges.

Our research also points to opportunities for future research, which should focus on deepening our understanding of how pandemics differentially impact life expectancy and lifespan inequality across various demographic groups and socioeconomic settings. Key areas include examining age-specific mortality patterns and the extent to which these shifts contribute to lifespan inequality, especially in contexts where healthcare access is limited. Additionally, research could further explore the role of gender disparities in mortality during pandemics, as well as the long-term socioeconomic effects of these gendered impacts on health and mortality. Comparative studies across countries and regions would also provide insights into how differences in healthcare infrastructure, policy responses, and social determinants influence outcomes, helping to identify best practices for mitigating mortality impacts. It is also crucial to consider not only the direct effects of pandemics on life expectancy and lifespan inequality but also their long-term, indirect impacts. These indirect effects include disruptions to essential healthcare services, increases in mental health issues, widening health disparities, and economic losses. Future research should also focus on evaluating these indirect effects at the subnational level, with particular attention to the collateral damage to healthcare systems, the surge in mental health challenges, and the growing burden of non-communicable diseases associated with pandemics. By understanding these indirect effects and their long-term consequences, policymakers can design interventions that are not only immediate but also sustainable, ensuring that public health systems are better prepared to address the multifaceted challenges posed by future pandemics.

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Appendix

Table A1: Country List

1918 Influenza Pandemic

Total Population	Male /Female
Denmark	Denmark
England	England
Finland	
Italy	Italy
Netherland	Netherland
Norway	Norway
Scotland	
Spain	
Sweden	Sweden
Switzerland	
USA	USA

HIV AIDS Pandemic

Afghanistan	Denmark	Liberia	Saint Kitts and Nevis
Albania	Djibouti	Libya	Saint Lucia
Algeria	Dominica	Lithuania	Samoa
American Samoa	Dominican Republic	Luxembourg	San Marino
Andorra	Ecuador	Madagascar	Sao Tome and Principe
Angola	Egypt	Malawi	Saudi Arabia
Antigua and Barbuda	El Salvador	Malaysia	Senegal
Argentina	Equatorial Guinea	Maldives	Serbia
Armenia	Eritrea	Mali	Seychelles
Australia	Estonia	Malta	Sierra Leone
Austria	Eswatini	Marshall Islands	Singapore
Azerbaijan	Ethiopia	Mauritania	Slovakia
Bahamas	Fiji	Mauritius	Slovenia
Bahrain	Finland	Mexico	Solomon Islands
Bangladesh	France	Micronesia	Somalia
Barbados	Gabon	Monaco	South Africa
Belarus	Gambia	Mongolia	South Sudan
Belgium	Georgia	Montenegro	Spain
Belize	Germany	Morocco	Sri Lanka
Benin	Ghana	Mozambique	State of Palestine
Bermuda	Greece	Myanmar	Sudan
Bhutan	Greenland	Namibia	Suriname
Bolivia	Grenada	Nauru	Sweden
Bosnia and Herzegovina	Guam	Nepal	Switzerland
Botswana	Guatemala	Netherlands	Syrian Arab Republic

Brazil	Guinea	New Zealand	Tajikistan
British Virgin Islands	Guinea-Bissau	Nicaragua	Thailand
Brunei Darussalam	Guyana	Niger	Timor-Leste
Bulgaria	Haiti	Nigeria	Togo
Burkina Faso	Honduras	Niue	Tokelau
Burundi	Hungary	North Macedonia	Tonga
Cabo Verde	Iceland	Northern Mariana Islands	Trinidad and Tobago
Cambodia	India	Norway	Tunisia
Cameroon	Indonesia	Oman	Türkiye
Canada	Iran	Pakistan	Turkmenistan
Central African Republic	Iraq	Palau	Tuvalu
Chad	Ireland	Panama	Uganda
Chile	Israel	Papua New Guinea	Ukraine
China	Italy	Paraguay	United Arab Emirates
Taiwan	Jamaica	Peru	United Kingdom
Colombia	Japan	Philippines	Tanzania
Comoros	Jordan	Poland	USA
Congo	Kazakhstan	Portugal	Uruguay
Cook Islands	Kenya	Puerto Rico	Uzbekistan
Costa Rica	Kiribati	Qatar	Vanuatu
Croatia	Kuwait	Republic of Korea	Venezuela
Cuba	Kyrgyzstan	Moldova	Viet Nam
Cyprus	Lao People's Democratic Republic	Romania	Yemen
Czechia	Latvia	Russian Federation	Zambia
Dem. People's Republic of Korea	Latvia	Rwanda	Zimbabwe
Democratic Republic of the Congo	Lesotho		

COVID-19 Pandemic

Total Population	Female /Male
Afghanistan	
Argentina	Argentina
Australia	Australia
Austria	Austria
Belgium	Belgium
Brazil	Brazil
Bulgaria	Bulgaria
Chile	Chile
Colombia	Colombia
Czechia	Czechia
Denmark	

Finland	
France	France
Georgia	
Germany	Germany
Greece	Greece
Guatemala	Guatemala
Hiti	
Hungary	Hungary
Indonesia	
Italy	Italy
Jamaica	
Japan	Japan
Lithuania	
Mexico	
Moldova	Moldova
Nepal	
Netherland	
New Zealand	New Zealand
Norway	Norway
Paraguay	Paraguay
Peru	Peru
Philippines	Philippines
Portugal	Portugal
Puerto Rico	Puerto Rico
Slovakia	Slovakia
Slovenia	Slovenia
Spain	Spain
Sweden	
Switzerland	
Taiwan	
Togo	Togo
UK	UK
Ukraine	Ukraine
USA	USA

Table A2: Life Expectancy Changes - Influenza Pandemic

	Total Population				Female Population				Male Population			
	1918		1919		1918		1919		1918		1919	
Country	Life Expectancy (All-cause death)	Life Expectancy (Cause Elimination -Influenza Death	Life Expectancy (All-cause death)	Life Expectancy (Cause Elimination -Influenza Death)	Life Expectancy (All-cause death)	Life Expectancy (Cause Elimination -Influenza Death	Life Expectancy (All-cause death)	Life Expectancy -(Cause Elimination -	Life Expectancy (All-cause death)	Life Expectancy (Cause Elimination -Influenza Death	Life Expectancy (All-cause death)	Life Expectancy -(Cause Elimination - Influenza Death)
Denmark	56.22	63.77	56.88	59.96	57.28	60.49	57.71	58.62	55.14	55.89	56.08	56.45
England	40.9	44.58	54.08	55.87	50.25	55.37	56.61	58.39	33.39	35.93	51.55	53.31
Finland	32.85	42.81	36.32	47.01								
Italy	25.82	41.7	31.68	42.61	28.34	36.33	44.88	45.98	23.52	27.67	38.62	39.35
Netherland	47.63	51.89	54.78	55.35	67.97	75.23	70.19	71.07	59.75	66.29	61.99	62.77
Norway	50.32	59.78	56.79	59.64	52.06	61.74	58..09	60.86	48.55	57.79	55.47	58.41
Scotland	48.87	52.68	50.80	53.07								
Spain	30.36	36.95	40.95	41.94								
Sweden	49.72	58.67	56.42	58.84	51.36	60.21	57.89	60.34	48.1	57.12	54.97	57.60
Switzerland	46.3	54.83	55.08	56.28								
USA	46.73	58.22	58.65	62.52	53.64	61.70	59.61	63.68	49.49	57.75	59.22	61.65

Table A3: Lifespan Inequality Changes - Influenza Pandemic

	Total Population				Female Population				Male Population			
	1918		1919		1918		1919		1918		1919	
Country	Theil Index (All-cause death)	Theil Index (Cause Elimination - Influenza Death	Theil Index (All-cause death)	Theil Index -(Cause Elimination - Influenza Death)	Theil Index (All-cause death)	Theil Index (Cause Elimination - Influenza Death	Theil Index (All-cause death)	Theil Index -(Cause Elimination - Influenza Death)	Theil Index (All-cause death)	Theil Index (Cause Elimination - Influenza Death	Theil Index (All-cause death)	Theil Index -(Cause Elimination - Influenza Death)
Denmark	17.62	15.07	17.91	17.23	16.50	15.07	16.77	17.23	18.73	15.07	18.99	17.23
England	29.88	23.92	19.63	15.72	24.66	20.86	17.92	17.01	32.47	31.04	21.28	20.36
Finland	35.13	31.43	33.44	29.60	Data not available							
Italy	53.53	44.05	36.11	32.39	53.41	42.25	34.35	30.71	52.99	44.43	37.58	33.72
Netherland	26.97	24.07	20.95	20.83	26.06	12.04	19.84	13.39	27.91	15.88	22.04	16.68
Norway	21.04	15.23	17.01	15.47	20.00	13.91	16.00	14.50	22.02	13.60	17.96	13.54
Scotland	25.45	19.74	23.70	19.31	Data not available							
Spain	49.63	43.27	37.53	37.17	Data not available							
Sweden	21.48	15.81	17.80	17.17	20.52	14.73	16.49	15.16	22.34	16.77	19.02	20.77
Switzerland	22.29	17.13	16.93	16.24	Data not available							
USA	60.45	46.32	48.95	40.03	57.63	42.89	45.22	36.77	63.13	49.66	52.83	43.44

Table A4: Life Expectancy Changes – COVID-19

	Total Population				Female Population				Male Population			
	2020		2021		2020		2021		2020		2021	
Country	Life Expectancy (All-cause death)	Life Expectancy (Cause Elimination -COVID	Life Expectancy (All-cause death)	Life Expectancy - (Cause Elimination -COVID	Life Expectancy (All-cause death)	Life Expectancy (Cause Elimination -COVID	Life Expectancy (All-cause death)	Life Expectancy (Cause Elimination -COVID	Life Expectancy (All-cause death)	Life Expectancy (Cause Elimination -COVID	Life Expectancy (All-cause death)	Life Expectancy (Cause Elimination -COVID
Afghanistan	62.58	62.6	61.98	62.14	Data not available							
Argentina	75.89	77.31	75.39	79.55	79.28	75.6	78.65	82.23	72.55	74.22	72.18	75.6
Australia	84.32	84.26	84.53	84.53	85.72	83.16	85.84	85.82	82.89	82.83	83.17	83.16
Austria	81.5	82.09	81.58	83.29	83.91	80.44	84.08	85.52	79.05	79.71	79.04	80.44
Belgium	80.79	81.37	81.88	83.16	83.05	81.02	84.3	84.92	78.52	79.91	79.43	81.02
Brazil	74.01	75.25	72.75	77.48	77.37	73.26	76.01	80.09	70.7	72.31	69.56	73.26
Bulgaria	73.65	74.33	71.8	74.61	77.51	71	76.01	79.01	77.51	78.95	68.44	71
Chile	79.38	80.71	78.94	82.41	82.04	79.39	81.44	84.41	76.74	78.35	76.47	79.39
Colombia	74.77	76.42	72.83	78.16	78.14	73.69	76.44	80.71	71.54	73.62	69.4	73.69
Czechia	78.57	79.35	77.73	80.58	81.54	76.98	80.89	83.26	75.63	76.16	74.67	76.98
Denmark	81.54	81.64	81.38	81.74	Data not available							
Finland	81.87	81.91	82.04	82.27	Data not available							
France	82.21	83.14	82.5	84.71	85.17	81.13	85.49	87.43	79.17	80.36	79.43	81.13
Georgia	72.77	73.26	71.69	74.19	Data not available							
Germany	81.15	81.49	80.63	81.63	83.65	78.94	83.22	84.06	78.66	79.03	78.08	78.94
Greece	80.91	81.22	80.11	81.11	83.54	79	82.85	84.62	78.38	78.73	77.49	79
Guatemala	71.8	72.77	69.24	71.77	75.55	68.37	72.65	74.6	68.26	69.55	66	68.37
Hiti	64.05	63.98	63.19	63.17	Data not available							
Hungary	75.73	76.36	74.53	77.79	79.03	73.88	77.92	80.88	72.32	73	71.1	73.88

Indonesia	68.81	68.85	67.57	68.05	Data not available							
Italy	82.4	83	82.85	84.81	84.69	82.38	85.1	86.57	80.04	81.09	80.52	82.38
Jamaica	71.87	71.92	70.5	71.57	Data not available							
Japan	84.69	84.59	84.78	84.79	87.72	81.82	87.73	87.69	81.61	81.53	81.8	81.82
Lithuania	75.07	75.52	73.72	75.53	Data not available							
Mexico	70.13	71.99	70.21	71.83	Data not available							
Moldova	70.17	70.91	68.85	71.25	74.85	65.95	73.55	76.44	65.69	66.3	64.44	65.95
Nepal	69.25	69.26	68.45	69.05	Data not available							
Netherland	81.64	82.1	81.69	81.69	Data not available							
New Zealand	82.74	82.65	82.45	82.36	84.57	80.66	84.32	84.42	80.88	80.97	80.58	80.66
Norway	83.2	83.14	83.23	83.31	84.88	81.69	84.88	84.99	81.47	81.48	81.56	81.69
Paraguay	73.18	73.88	70.26	74.16	76.16	71.21	73.38	77.96	70.4	71.21	67.43	71.21
Peru	73.67	79.4	72.38	87.02	76.82	83.65	74.75	84.75	70.81	78.19	70.12	83.65
Philippines	72.12	72.25	69.27	70.02	74	67.77	71.48	72.19	70.24	70.42	67.17	67.77
Portugal	81.05	81.43	81.04	82.41	83.98	78.91	84.08	85.24	77.95	78.47	77.85	78.91
Puerto Rico	78.04	78.55	80.16	81.56	82.59	77.12	84.52	85.85	73.64	74.29	75.86	77.12
Slovakia	77.01	77.46	74.91	77.74	80.36	73.72	78.43	81.06	73.6	74.14	71.49	73.72
Slovenia	80.44	81.37	80.69	83.32	83.31	79.43	83.84	86.26	77.63	78.71	77.65	79.43
Spain	82.29	83.19	83.01	84.95	85.01	81.83	85.77	87.33	79.55	80.81	80.21	81.83
Sweden	82.43	83.02	82.98	84.39	Data not available							
Switzerland	83.07	83.77	83.99	85.31	Data not available							
Taiwan	80.89	80.8	81.01	80.96	Data not available							
Togo	61.04	60.95	61.62	61.55	61.58	60.8	62.39	62.34	60.49	60.41	60.85	60.8
UK	80.43	81.6	80.74	83.73	82.45	81.12	82.77	85.34	78.43	80.56	78.72	81.12
Ukraine	72.57	72.85	71.62	73.18	77.37	67.56	76.7	78.49	67.59	68.02	66.53	67.56
USA	77.41	78.57	77.2	78.84	80.31	77.15	80.24	81.7	74.64	75.88	74.3	77.15

Table A5: Lifespan inequality changes – COVID-19

Country	Total Population				Female Population				Male Population			
	2020		2021		2020		2021		2020		2021	
	Theil Index (All-cause death)	Theil Index (Cause Elimination - COVID	Theil Index (All-cause death)	Theil Index - (Cause Elimination - COVID	Theil Index (All-cause death)	Theil Index (Cause Elimination - COVID	Theil Index (All-cause death)	Theil Index - (Cause Elimination - COVID	Theil Index (All-cause death)	Theil Index (Cause Elimination - COVID	Theil Index (All-cause death)	Theil Index - (Cause Elimination - COVID
Afghanistan	9.83	10.15	10.06	10.21	Data not available							
Argentina	3.18	3.33	3.19	3.06	3.36	2.95	2.84	2.68	2.81	3.47	3.37	3.3
Australia	1.34	1.61	1.28	1.54	1.44	1.49	1.16	1.43	1.22	1.71	1.36	1.63
Austria	1.63	1.89	1.68	1.85	1.85	1.59	1.33	1.52	1.33	2.11	1.93	2.12
Belgium	1.72	2.55	1.79	3.41	1.89	2.75	1.51	3.38	1.47	2.09	1.97	2.13
Brazil	3.91	4.32	4.05	5.08	4.65	4.82	3.24	3.79	3.01	4.76	4.71	4.54
Bulgaria	2.56	2.78	2.62	2.68	2.07	2.31	3.24	3.24	2.07	2.14	2.83	2.92
Chile	2.34	2.5	2.45	2.4	2.65	2.09	2.09	2.03	1.93	2.74	2.72	2.7
Colombia	3.72	3.87	4.06	3.88	4.39	3.07	3.16	2.97	2.91	4.45	4.8	4.7
Czechia	1.73	1.98	1.79	1.96	1.93	1.64	1.45	1.59	1.37	2.19	1.98	2.17
Denmark	1.64	1.9	1.53	1.78	Data not available							
Finland	1.74	2	2	1.82	Data not available							
France	1.92	2.15	1.92	2.06	2.2	1.75	1.52	1.65	1.53	2.42	2.2	2.4
Georgia	2.84	3.08	2.88	3.13	Data not available							
Germany	1.76	2.02	1.79	2.01	1.95	1.74	1.49	1.72	1.47	2.19	1.99	2.2
Greece	1.8	1.98	1.83	2.7	2.09	1.61	1.47	1.24	1.45	2.28	2.13	2.21
Guatemala	5.29	5.4	5.25	5.21	5.91	4.65	4.48	4.44	4.53	5.97	5.9	5.93
Hiti	9.58	9.9	9.77	10.09	Data not available							
Hungary	2.12	2.34	2.2	2.25	2.34	1.93	1.86	1.88	1.7	2.57	2.34	2.39
Indonesia	4.8	5.05	4.91	5.19	Data not available							

Italy	1.45	1.7	1.49	1.64	0.01	1.44	1.22	1.4	1.63	1.86	1.67	1.84
Jamaica	3.53	3.79	3.71	3.65	Data not available							
Japan	1.54	1.79	1.43	1.69	0.01	1.53	1.19	1.47	1.68	1.94	1.54	1.8
Lithuania	2.55	2.81	2.65	2.77	Data not available							
Mexico	4.22	4.31	4.16	4.24	Data not available							
Moldova	3.39	3.6	3.4	3.56	3.76	2.85	2.69	2.68	2.68	4.03	3.77	4.02
Nepal	5.36	5.64	5.51	5.5	Data not available							
Netherland	1.55	1.82	1.55	1.84	Data not available							
New Zealand	1.97	2.23	2.07	2.33	3.36	1.94	3.53	2.03	4.44	2.48	4.64	2.58
Norway	1.45	1.74	1.4	1.67	1.21	1.52	1.19	1.46	1.63	1.91	1.55	1.82
Paraguay	4.4	4.6	4.29	4.19	4.92	3.96	3.64	3.4	3.76	5.09	4.81	4.75
Peru	3.52	3.11	3.75	2.06	3.91	2.72	3.29	2.22	3.02	3.04	4.14	2.54
Philippines	4.69	4.95	4.71	4.9	5.12	4.43	4.19	4.38	4.17	5.37	5.12	5.33
Portugal	1.7	1.95	1.72	1.83	1.33	1.6	1.37	1.52	1.97	2.21	1.96	2.17
Puerto Rico	3.67	3.84	3.06	3.04	4.24	3.09	2.37	2.32	2.93	4.39	3.6	3.62
Slovakia	2.24	2.49	2.3	2.43	2.52	2.02	1.85	1.92	1.78	2.76	2.54	2.7
Slovenia	1.54	1.78	1.61	1.73	1.77	1.4	1.24	1.34	1.17	2.01	1.81	1.99
Spain	1.52	1.73	1.54	1.63	1.71	1.46	1.25	1.35	1.23	1.9	1.72	1.89
Sweden	1.48	1.74	1.17	1.65	Data not available							
Switzerland	1.55	1.81	1.4	1.65	Data not available							
Taiwan	2.14	2.39	2.11	2.35	Data not available							
Togo	11.44	11.78	11.02	11.36	11.6	11.6	10.74	11.08	11.25	11.95	11.28	11.62
UK	1.97	2.16	3.04	2.04	3.44	1.86	1.73	1.73	2.4	2.12	3.35	3.57
Ukraine	3	3.24	2.03	3.2	3.39	2.46	2.29	2.36	2.21	3.57	2.28	2.37
USA	2.98	3.16	3.12	3.2	3.08	2.58	2.54	2.62	1.68	3.31	3.28	3.39

Table A6: Summary Statistics – 1918 Influenza Pandemic

Year	Changes in Life Expectancy-Total Population				Changes in Lifespan Inequality-Total Population			
	Mean	Median	SD	IQR	Mean	Median	SD	IQR
1918	-6.79	-6.59	0.80	4.69	6.13	5.71	3.25	2.67
1919	-2.20	0.43	1.42	1.86	2.62	1.53	2.67	3.28
	Changes in Life Expectancy-Female				Changes in Lifespan Inequality-Female			
	Mean	Median	SD	IQR	Mean	Median	SD	IQR
	-4.75	-3.49	3.48	5.86	5.63	4.80	4.91	6.50
	Changes in Life Expectancy-Male				Changes in Lifespan Inequality-Male			
	Mean	Median	SD	IQR	Mean	Median	SD	IQR
	-4.01	-2.79	3.49	4.90	3.92	3.85	6.48	3.61

Table A7: Summary Statistics – HIV/AIDS Pandemic

HIV -Life Expectancy -Total Population					HIV -Lifespan inequality -Total Population				
Year	Mean	Median	SD	IQR	Year	Mean	Median	SD	IQR
1990	-0.16	0.07	0.95	0.09	1990	-0.13	-0.27	0.69	0.1
1991	-0.22	0.06	1.07	0.12	1991	-0.08	-0.27	0.79	0.1
1992	-0.33	0.06	1.28	0.16	1992	-0.02	-0.26	0.92	0.09
1993	-0.43	0.05	1.49	0.22	1993	0.04	-0.25	1.05	0.11
1994	-0.55	0.04	1.77	0.27	1994	0.11	-0.25	1.21	0.13
1995	-0.68	0.03	2.07	0.33	1995	0.18	-0.25	1.36	0.16
1996	-0.79	0.03	2.36	0.4	1996	0.24	-0.25	1.5	0.18
1997	-0.88	0.03	2.63	0.45	1997	0.29	-0.24	1.62	0.19
1998	-0.98	0.03	2.9	0.46	1998	0.33	-0.25	1.72	0.22
1999	-1.04	0.02	3.09	0.52	1999	0.38	-0.24	1.8	0.26
2000	-1.17	0.01	3.3	0.62	2000	0.42	-0.24	1.87	0.3
2001	-1.23	0.01	3.46	0.67	2001	0.43	-0.24	1.88	0.31
2002	-1.25	0.02	3.47	0.72	2002	0.45	-0.24	1.93	0.32
2003	-1.24	0.01	3.53	0.73	2003	0.44	-0.23	1.89	0.33
2004	-1.26	0.01	3.46	0.78	2004	0.42	-0.23	1.84	0.36
2005	-1.21	0.01	3.33	0.7	2005	0.39	-0.22	1.73	0.37
2006	-1.13	0	3.11	0.71	2006	0.34	-0.22	1.58	0.34
2007	-1.04	-0.01	2.86	0.69	2007	0.29	-0.22	1.44	0.31
2008	-0.94	-0.01	2.56	0.6	2008	0.24	-0.22	1.3	0.29
2009	-0.85	-0.02	2.3	0.63	2009	0.19	-0.21	1.14	0.29
2010	-0.79	-0.02	2.1	0.6	2010	0.15	-0.21	1.01	0.27
2011	-0.74	-0.02	1.94	0.58	2011	0.12	-0.22	0.91	0.26
2012	-0.68	-0.02	1.84	0.55	2012	0.09	-0.22	0.85	0.24
2013	-0.65	-0.03	1.76	0.5	2013	0.06	-0.22	0.8	0.24
2014	-0.62	-0.03	1.69	0.48	2014	0.05	-0.21	0.77	0.23
2015	-0.59	-0.04	1.62	0.46	2015	0.03	-0.21	0.73	0.23

2016	-0.55	-0.03	1.52	0.44	2016	0	-0.21	0.67	0.21
2017	-0.51	-0.03	1.43	0.41	2017	-0.02	-0.21	0.62	0.19
2018	-0.47	-0.02	1.33	0.38	2018	-0.04	-0.22	0.56	0.17

	Changes in Life Expectancy-Female				Changes in Lifespan Inequality-Female			
	Mean	Median	SD	IQR	Mean	Median	SD	IQR
	-0.84	0.05	2.68	0.33	0.14	-0.26	1.23	0.15
	Changes in Life Expectancy-Male				Changes in Lifespan Inequality-Male			
	Mean	Median	SD	IQR	Mean	Median	SD	IQR
	-0.66	0.00	2.24	0.41	0.02	-0.25	1.00	0.15

Table A8: Summary Statistics - COVID-19 Pandemic

Year	Changes in Life Expectancy-Total Population				Changes in Lifespan Inequality-Total Population			
	Mean	Median	SD	IQR	Mean	Median	SD	IQR
2020	-0.65	-0.51	0.92	0.85	-0.24	-0.25	0.14	0.05
2021	-1.94	-1.55	2.37	2.15	-0.16	-0.15	0.48	0.21
	Changes in Life Expectancy-Female				Changes in Lifespan Inequality-Female			
	Mean	Median	SD	IQR	Mean	Median	SD	IQR
	-1.48	-0.87	1.79	1.68	0.13	0.01	0.68	0.67
	Changes in Life Expectancy-Male				Changes in Lifespan Inequality-Male			
	Mean	Median	SD	IQR	Mean	Median	SD	IQR
	-1.61	-1.26	2.02	1.59	-0.34	-0.24	0.70	0.69

Chapter 5: Conclusion

The growing body of research into lifespan inequality and life expectancy highlights the need to understand the complex social, economic, and demographic factors that drive these variables. In recent decades, the global landscape of public health has been marked by both improvements in life expectancy and significant challenges posed by health crises, violent crime, and geographical disparities (Aburto et al., 2021). This thesis explored these critical issues through three interrelated studies that investigated the impact of geographical disparities, homicide, and pandemics on life expectancy and lifespan inequality at the state level in the US and in a global context. The first paper, "State-Level Differences in Life Expectancy and Lifespan Inequality: Is It a Matter of Socioeconomic Inequalities?", addressed how variations in life expectancy and lifespan inequality across U.S. states are shaped by socioeconomic factors such as education, income inequality, and healthcare resources. The second paper, "Homicides and Its Impact on Life Expectancy and Lifespan Inequality at the State Level in the USA", explored how homicides contribute to life expectancy and lifespan inequality across US states from 1968 to 2020 and the determinants of the impact of homicide on life expectancy and lifespan inequality. The third paper, "A Tale of three pandemics: The Impact on life expectancy and Lifespan Inequality", investigated the effects of three pandemics (the 1918 influenza, HIV/AIDS, and COVID-19) on life expectancy and lifespan inequality at the country level.

5.1 Major Findings

The second chapter explored how socioeconomic factors influence lifespan inequality across US states. Over 55 years, a divergence in lifespan inequality between genders was observed, with males experiencing more fluctuations compared to females, whose lifespan inequality was relatively stable. The study also revealed substantial state-level variations, with Mississippi consistently exhibiting the highest lifespan inequality, while Massachusetts and Minnesota had the lowest. Geographic disparities in life expectancy and lifespan inequality have persisted, particularly in some Midwestern states, where life expectancy gains have plateaued or declined.

A significant negative correlation exists between life expectancy and lifespan inequality for both genders. A key point of the negative correlation between life expectancy and lifespan inequality is due to differences in mortality at younger ages. States experiencing fewer early to mid-adulthood deaths see a “compression” of mortality that increases life expectancy while reducing lifespan variability (Acciai & Firebaugh, 2019; Sasson, 2016). However, rising mortality linked to “deaths of despair” has widened within-state and cross-state disparities (Case & Deaton, 2015;

Fenelon, 2013; Seltzer, 2020). In contrast, once individuals reach older ages, federal policies like Medicare and Social Security tend to level out health and economic disparities, thereby making state differences in variability less pronounced among older adults (Cosby et al., 2019; Montez et al., 2020; Sofer, 2018).

Education emerged as the strongest predictor of reduced lifespan inequality, with higher percentages of high school and college graduates associated with more uniform age-at-death distributions. Other factors like income inequality (measured by the Gini index), violent crime rates, cigarette consumption, and CO_2 emissions were positively correlated with higher lifespan inequality. Conversely, factors such as physician availability and the prevalence of health insurance were linked to lower lifespan inequality. The paper concluded by emphasizing the importance of policies aimed at addressing socioeconomic and health-related disparities to promote more equitable health outcomes across all regions.

The third chapter examined the impact of homicides on life expectancy and lifespan inequality across US states, shedding light on how these outcomes are shaped by demographic, socioeconomic, government expenditure, and policy-related factors. The findings revealed regional disparities, with Southern states experiencing the highest losses in life expectancy and the greatest increases in lifespan inequality due to homicide, compared to relatively lower impacts in Northeastern states. Males consistently face greater homicide-related impacts than females, although the impact on women is substantial in certain states.

The study also identified education as a crucial mitigating factor, with higher high school graduation rates linked to smaller impacts of homicide on life expectancy and lifespan inequality. The disproportionate impact of homicides on Black populations underscores systemic inequities, reflecting the heightened exposure of marginalized communities to violence. Among demographic groups, individuals aged 25–34 emerged as particularly vulnerable, amplifying homicide's effects on both outcomes. These findings underscore the need for policies that address structural issues, such as racism and age, to tackle the root causes of violence and reduce its disproportionate impact on vulnerable populations.

Policy measures, such as the absence of Stand Your Ground laws and increased population density are linked to less pronounced effects on both life expectancy and lifespan inequality. Structural expenditures, such as corrections and judicial spending, influenced overall mortality patterns and homicide-related mortality among younger adults, affecting both life expectancy and lifespan inequality. While corrections spending often perpetuates cycles of violence through punitive policies, judicial spending showed potential benefits by improving court efficiency and legal processes. Conversely, spending on police, health, and welfare demonstrated stronger associations with lifespan inequality, targeting younger populations and reducing premature deaths. However, the complex relationship between government expenditure and homicide suggests further investigation, focusing on developing independent measures of program effectiveness and evaluating their direct and indirect impacts on homicide rates, life expectancy, and lifespan inequality.

Finally, the fourth chapter provided a comprehensive comparative analysis of the impacts of three major pandemics: 1918 Influenza, HIV/AIDS, and COVID-19 on life expectancy and lifespan inequality, examining their unique mortality patterns and demographic effects. Each pandemic had distinct demographic targets and magnitudes of impact on mortality outcomes, reflecting variations in their transmission dynamics, and affected populations.

The 1918 Influenza pandemic, marked by its rapid onset and widespread reach, caused an unprecedented and immediate reduction in life expectancy. This pandemic had a "W-shaped" mortality curve, with high death rates for young adults (ages 20–40). This unusual age distribution led to a sharp increase in lifespan inequality, reflecting significant mortality disparities. Young adults, typically a low-risk group for infectious diseases, were disproportionately affected, challenging existing understandings of disease dynamics and exacerbating social and economic disruptions. The high mortality among this age group heightened lifespan inequality the most among the pandemics studied in this chapter. The HIV/AIDS pandemic, which emerged in the 1980s, had a more prolonged and transformative impact, peaking in the 1990s and early 2000s, particularly in sub-Saharan Africa and among marginalized populations worldwide. Life expectancy reductions were lower compared to the influenza pandemic but more sustained over time, with significant gender disparities. Women experienced greater reductions in life expectancy and increases in lifespan inequality, reflecting the social and economic vulnerabilities worsened by HIV. The COVID-19 pandemic, beginning in 2020, caused substantial losses in life expectancy globally and recorded a sharp increase in 2021 compared to 2020. Unlike the previous pandemics, COVID-19 mortality was concentrated among older populations, particularly those aged 60 and above, which led to an overall smaller effect on lifespan inequality.

The third study highlighted the importance of some demographic factors such as age and gender in determining the impacts on life expectancy and lifespan inequality, as well as the critical role of sustained and targeted policy interventions to mitigate these effects. It also underscores the need for gender-sensitive approaches and the significance of addressing social and economic vulnerabilities in pandemic responses.

5.2. Policy Implications

The results of this study have several important implications for policy. Especially, the findings from the study suggest that reducing lifespan inequality requires a multifaceted policy approach that tackles the key socioeconomic determinants of lifespan inequality.

Education was identified as a crucial predictor of lifespan inequality, with higher educational attainment linked to longer life expectancy and lower lifespan inequality. This makes education a key lever in public health interventions, suggesting that policies that enhance access to quality education are likely to yield long-term health benefits. Improving education not only improves individuals' earning potential but also enhances their health literacy, access to healthcare, and capacity to make informed lifestyle choices (Raghupathi and Raghupathi, 2020; Hahn & Truman, 2015). Prioritizing investments in early childhood education, strengthening public schools, and providing adult learning programs are essential areas of focus, especially in underprivileged areas to ensure equitable access to education for all citizens, regardless of their background. By elevating educational outcomes, governments will be able to reduce the health disparities which lead to lifespan inequality.

The link between homicide and lifespan inequality underscores the importance of both public safety and community-based strategies. While comprehensive crime reduction measures may involve law enforcement resources, they should also emphasize prevention. Preventive initiatives, particularly youth mentorship programs and accessible mental health services, are crucial (Sampson et al., 1997; Gottfredson et al., 2004; Catalano et al., 2004; David-Ferdon et al., 2016; Sharkey, 2018). Therefore, governments should invest in programs that expand mentorship, improve educational opportunities, and foster community engagement for populations most affected by homicide. Such efforts can reduce violence, enhance public safety, and ultimately yield long-term gains in both life expectancy and lifespan equality. By targeting underlying issues such as poverty, limited education, and social isolation through equitable funding and policy reforms, these strategies not only help curb violence in the short term but also mitigate the long-term consequences of homicide on lifespan inequality.

The observed geographic disparities in life expectancy and lifespan inequality further highlight that different states face distinct public health challenges. For instance, states like Mississippi, West Virginia, and Oklahoma exhibit notably poor outcomes, demonstrating the need for targeted, context-specific measures. A one-size-fits-all approach to reducing health inequality is therefore unlikely to be effective. Instead, federal and state governments should collaborate to develop tailored solutions based on each state's demographic, economic, and healthcare realities. By integrating these localized strategies with efforts to reduce violent crime, policymakers can address the broader social determinants of health that shape life expectancy and lifespan inequality across diverse regions.

The study also underscores the importance of healthcare access in explaining differences in lifespan inequality. Policies that expand access to healthcare, particularly those that address geographical disparities in low insurance coverage rates or physician shortages, should therefore be prioritized. In the US, this could include extending Medicaid eligibility, ensuring that marketplaces under the Affordable Care Act (ACA) are robust, and encouraging the expansion of rural health services. Preventive healthcare, in particular, stands out as an area for investment. By improving access to preventive services such as regular check-ups, screenings, and vaccinations, policymakers can prevent many of the early deaths that drive lifespan inequality (Fuchs & Eggleston, 2018; Hamson et al., 2023). Expanding primary care networks, incentivizing physicians to practice in underserved areas, and promoting telemedicine may also help bridge healthcare access gaps, leading to more equitable health outcomes (Anawade et al., 2024; Hoagland & Kipping, 2024). However, the financial and technological barriers to expanding healthcare access remain substantial, especially in low-income or rural areas, requiring innovative solutions from local and national governments.

The healthcare challenges for lifespan inequality are not just national, but global. Given the severe impact of pandemics like the Spanish flu and COVID-19 on lifespan inequality, global health systems should prioritize building robust surveillance networks. Early detection systems would allow for rapid intervention, limiting the spread of infectious diseases and mitigating the adverse effects on life expectancy and lifespan inequality. This could be done through collaborations between governments, global health organizations (e.g., WHO), and technology firms to improve data sharing and predictive modeling for emerging diseases (Williams et al., 2023). To prevent similar future impacts on life expectancy and lifespan inequality, governments must ensure equitable distribution of vaccines and treatments. Especially this approach should explicitly include children, ensuring that testing, treatment, and preventive services are expanded across all age groups during pandemics to reduce uneven impacts on lifespan.

Moreover, national governments must focus on building robust healthcare systems that can handle surges in patient care during pandemics without compromising ongoing medical services.

Investment in hospital capacity, trained personnel, and emergency resources can greatly mitigate the impact of future pandemics on life expectancy and lifespan inequality (Hendrickson, 2020; Williams et al., 2023; Srivastava Neha Pandey, 2024). Reducing inequality in healthcare access and improving the overall living conditions of vulnerable populations can make societies more resilient in the face of future pandemics and prevent large changes in lifespan inequality. However, the challenge lies in maintaining these systems in the absence of an immediate crisis and ensuring equitable access to resources during emergencies (Vargas & Narayan, 2020; Etienne et al., 2020).

Gender-specific differences in mortality rates observed for pandemics like HIV/AIDS and COVID-19 highlight the need for tailored health interventions. While HIV/AIDS disproportionately impacted women by increasing lifespan inequality, COVID-19 had a more pronounced negative effect on men's lifespan inequality, revealing distinct gender-based disparities in both pandemics. Therefore, health policies should integrate demographic-specific strategies that address the unique vulnerabilities of different population groups, including targeted interventions for men, women, and marginalized communities. Such policies can help reduce lifespan inequality and ensure that no population segment is left behind during public health emergencies.

Racial disparities in life expectancy and lifespan inequality also demand attention, especially among the Black population. The correlation between a high proportion of Black residents and the changes in life expectancy and lifespan inequality due to homicide highlights the need to address racism and socioeconomic inequalities. Many Black communities face heightened levels of poverty, unemployment, and disinvestment, which create conditions conducive to violence (Zimmerman et al., 2024). Policies aimed at improving housing, access to quality education, healthcare, and job opportunities in these communities would not only reduce homicides but also address the root causes of social inequality (Elo et al., 2019; Johnson et al., 2021). This approach would have a direct and positive impact on reducing the disproportionate burden of violent crime on Black populations, thereby improving life expectancy and lifespan equality.

The mixed results of government expenditures on life expectancy and lifespan inequality highlight the necessity of focusing on reallocating resources toward community policing and restorative justice programs rather than punitive correctional measures (Beckett, 2022). Furthermore, revisiting Stand Your Ground laws and implementing stricter gun control measures in states where they are prevalent could mitigate homicide-related life expectancy and lifespan inequality impacts (Levy et al., 2019).

5.3 Study Contributions

This thesis makes several key contributions to the fields of demographic and health research. First, it extends the theoretical understanding of lifespan inequality by examining how pandemics, homicide, and socioeconomic factors collectively shape life expectancy and lifespan inequality. The inclusion of regional and state-level analyses provides a novel perspective, demonstrating the importance of localized effects and government policy on lifespan inequality.

Second, the research provides new insights into the impacts of health crises, such as pandemics, on lifespan inequality. By comparing the 1918 influenza, HIV/AIDS, and COVID-19 pandemics, the study offers a comprehensive analysis of how pandemics disproportionately affect vulnerable populations and exacerbate health disparities. This research fills a critical gap in the literature on the intersection of public health and lifespan inequality, particularly in times of crisis.

Third, the study on homicide and lifespan inequality highlights the often-overlooked role of homicide in shaping health outcomes. By linking socioeconomic inequality with homicide and its impact on life expectancy and lifespan inequality, this thesis contributes to a more holistic understanding of the social determinants of health and underscores the importance of integrated social and public health policies.

The findings of this thesis also have implications for global policy frameworks, as articulated in the United Nations Sustainable Development Goals (SDGs). The study's focus on health crises, socioeconomic inequalities, and violent crime aligns with several key SDGs. In particular, SDG 3 (Good Health and Well-being) emphasizes universal health coverage and extending life expectancy for all goals directly linked to reducing lifespan inequality. The analysis presented here shows how progress on health outcomes influences, and is influenced by other SDGs, notably SDG 1 (End poverty in all its forms everywhere) and SDG 10 (Reduce inequality within and among countries), since poverty and inequality are known risk factors for both poor health and violent crime. Similarly, addressing lifespan inequality intersects with SDG 4 (Quality education) by encouraging educational investments and SDG 8 (Decent work and economic growth) through its impact on labor force participation and economic development. Furthermore, this work contributes to SDG 16 (Peace, Justice, and Strong Institutions) by highlighting the need to reduce violence and related death rates, given homicide's disproportionate effect on younger populations and marginalized communities. Finally, the research aligns with global efforts to measure and address inequalities through instruments like the Inequality-Adjusted Human Development Index (IHDI), reinforcing the importance of tackling lifespan inequality at local, regional, and international levels.

In addition to these global perspectives, the thesis offers practical policy insights that can guide state and national efforts to address lifespan inequality. By emphasizing the need for targeted interventions such as tackling socioeconomic disparities, improving public health infrastructure, and reducing homicide the research underscores how evidence-based strategies can produce more equitable health outcomes. Ultimately, these findings serve as a resource for governments, international organizations, and policymakers working to achieve a more inclusive, resilient, and sustainable future for all.

5.4 Limitations and Future Research Directions

The findings and limitations of this study highlight several key opportunities for future research. First, considering geographical disparities, life expectancy, and lifespan inequality, our analysis focuses solely on the state level in the USA. However, mortality rates and life expectancy can vary significantly across substate geographic levels, such as counties or metropolitan areas (Chetty et al. 2016; Elo et al. 2019; Ezzati et al. 2008). Thus, it would be valuable to explore how lifespan inequality differs across substate geographic levels and examine the determinants driving these variations. Further, comparative studies with other countries could also shed light on how different socioeconomic and demographic factors affect in particular, lifespan inequality, offering valuable contributions to health and population studies.

Second, all three studies focused on life expectancy and lifespan inequality. However, measuring healthy lifespan inequality (HLI) instead of lifespan inequality is crucial because it emphasizes the variability in the quality of health across individuals, not just the length of life (Permanyer et al., 2022). HLI focuses on disparities in the number of healthy years lived, capturing how long people remain free from illness or disability, rather than merely their total lifespan (Permanyer et al., 2022). Therefore, this study could be expanded further by studying HLI which provides better insights into the variation in age at death, focusing on both the timing of health deterioration and the overall distribution of population health.

Third, reliance on historical and contemporary datasets, which may vary in quality and completeness across regions and periods is a key limitation. For example, mortality data for the 1918 influenza is incomplete, particularly for low-income regions, and the 1918 influenza analysis in Chapter 3 was limited to 11 countries, which may result in underestimating the full impact of the 1918 influenza on life expectancy and lifespan inequality. Moreover, important differences across countries are lost when those countries lack sufficient data to be included in the analysis. Also, the study considered only two consecutive years. Therefore, future research should focus on longitudinal data to analyze how lifespan inequality evolves, both during and after a pandemic. This would allow researchers to capture long-term effects on mortality and explore the recovery trajectories of affected populations. For example, studies could track how life expectancy and lifespan inequality return to pre-crisis levels (if at all) after pandemics like COVID-19 or the 1918 influenza.

Fourth, a promising direction for future research is to investigate how socioeconomic and demographic factors, healthcare system preparedness, and policy interventions affect life expectancy and lifespan inequality during pandemics. Studies could explore how countries with more robust health systems or those that implement early public health interventions fare in terms of mitigating lifespan inequality compared to those with weaker systems. Evaluating the effectiveness of vaccination campaigns, economic support policies, and healthcare accessibility in reducing inequality would provide valuable insights for future pandemic preparedness.

Finally, one of the studies offers significant strengths in analyzing the impact of homicide on life expectancy and lifespan inequality across U.S. states from 1968 to 2020. By utilizing a comprehensive dataset from the U.S. Mortality Database and CDC, the research captures trends over five decades, providing a robust foundation for understanding long-term changes. However, it concentrates primarily on homicides as a cause of premature death, leaving other significant causes, such as drug overdoses or accidents, underexplored. Moreover, the study touches on the role of state-level policies, such as Universal Background Checks, but does not deeply explore the varying effects of different legal frameworks on lifespan inequality. Future research could address these limitations by exploring other causes of premature death alongside homicide would offer a more comprehensive view of the factors driving life expectancy and lifespan inequality. Additionally, investigating the interaction between socioeconomic conditions, state-specific laws, and homicide rates could provide deeper insights into how policy interventions can reduce lifespan inequality. Moreover, a focused exploration of the relationship between income inequality and lifespan inequality as a proposed article in the study could shed further light on the economic drivers of health disparities, thereby pointing to additional, potentially powerful policy levers for reducing inequality.

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Appendix -Co-Authorship Form

THE UNIVERSITY OF WAIKATO

Co-Authorship Form

School of Graduate Research
The University of Waikato
Private Bag 3105
Hamilton 3240, New Zealand
Phone +64 7 838 5096
Email: SGR@waikato.ac.nz
Website: http://www.waikato.ac.nz/students/research-degre

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Nature of contribution by PhD candidate	Data Analysis, Result interpretation, preparing the full draft, conference presentation, published as working papers
Extent of contribution by PhD candidate (%)	70

CO-AUTHORS

Name	Nature of Contribution
Michael P. Cameron	Guidance, critical feedback, Proof Reading and assistance with working paper submission
Susan Olivia	Guidance, critical feedback
Les Oxley	Guidance, critical feedback

Certification by Co-Authors

The undersigned hereby certify that:

- the above statement correctly reflects the nature and extent of the PhD candidate's contribution to this work, and the nature of the contribution of each of the co-authors; and
- that the candidate wrote all or the majority of the text.

Name	Signature	Date
Michael P. Cameron	[signature]	30/1/25
Susan Olivia	[signature]	30/1/25
Les Oxley	[signature]	30/1/25

July 2015

THE UNIVERSITY OF
WAIKATO

Co-Authorship Form

School of Graduate Research
The University of Waikato
Private Bag 3105
Hamilton 3240, New Zealand
Phone +64 7 838 5096
Email: SGR@waikato.ac.nz
Website: http://www.waikato.ac.nz/students/research-degre

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Nature of contribution by PhD candidate	Data Analysis, Result interpretation, preparing the full draft, prepare for publication as working paper
Extent of contribution by PhD candidate (%)	70

CO-AUTHORS

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Les Oxley	Guidance, critical feedback

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- that the candidate wrote all or the majority of the text.

Name	Signature	Date
Michael P. Cameron	[signature]	30/1/25
Susan Olivia	[signature]	30/1/25
Les Oxley	[signature]	30/1/25

July 2015

THE UNIVERSITY OF
WAIKATO

School of Graduate Research
The University of Waikato
Private Bag 3105
Hamilton 3240, New Zealand
Phone +64 7 838 5096
Email: SGR@waikato.ac.nz
Website: http://www.waikato.ac.nz/students/research-degre

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Nature of contribution by PhD candidate	Data Analysis, Result interpretation, preparing the final draft,Prepare for publishcation as working papers
Extent of contribution by PhD candidate (%)	70

CO-AUTHORS

Name	Nature of Contribution
Michael P. Cameron	Guidance, critical feedback, and assistance with work paper submission
Susan Olivia	Guidance, critical feedback
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Certification by Co-Authors

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- that the candidate wrote all or the majority of the text.

Name	Signature	Date
Michael P. Cameron	[signature]	30/1/25
Susan Olivia	[signature]	30/1/25
Les Oxley	[signature]	29/1/25

July 2015