SSM - Population Health 19 (2022) 101213

Contents lists available at ScienceDirect

SSM - Population Health

journal homepage: www.elsevier.com/locate/ssmph

Trends in lifespan variation across the spectrum of rural and urban places in the United States, 1990–2017

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ARTICLE INFO

Keywords:
Rural health
Rural mortality penalty
Lifespan variation
Lifespan disparity
Mortality compression

ABSTRACT

Mortality disparities between urban and rural areas in the United States widened in recent decades as mortality improvements in rural areas slowed. Although the existence of a rural mortality penalty is well-documented, previous research in this area has focused almost exclusively on differences in average levels of mortality *between* rural and urban areas rather than differences in levels of lifespan variation *within* rural and urban areas. This oversight is important because monitoring trends in lifespan variation provides unique insights into levels of inequality in the age-at-death distribution within a population. Does the rural mortality penalty in life expectancy extend to lifespan variation? We used U.S. Multiple Cause of Death data files to measure life disparity at birth ($e_0^\dagger$) from 1990 to 2017. We found that the rural mortality penalty extends to lifespan variation as large metropolitan areas had greater improvements in life disparity than nonmetropolitan areas. Beginning around 2011, all areas began to show increased life disparity with the largest increases occurring in nonmetropolitan areas. Age decomposition results showed that the nonmetropolitan increases were due to rising working-age mortality. Greater variability in the age-at-death distribution represents an additional dimension of inequality for Americans living in rural places.

1. Introduction

Beginning in the early 1990s, slower progress in reducing mortality in rural areas of the United States led to widening urban-rural disparities in mortality termed the "rural mortality penalty" (Cosby et al., 2008, 2019; Elo et al., 2019; Monnat, 2020; Singh & Siahpush, 2014; Stein et al., 2017; Vierboom et al., 2019). Prior research on the rural mortality penalty in the U.S. has focused on revealing heterogeneity along the spectrum of rural and urban places, finding the urban-rural dichotomy overly broad to accurately describe the mortality experiences of rural and urban populations (Elo et al., 2019; James 2014; Monnat 2020; Vierboom et al., 2019). However, there is an additional source of heterogeneity that has yet to be examined regarding the rural mortality penalty. Studies of urban-rural mortality disparities have focused exclusively on differences in average levels of mortality between rural and urban areas and have not examined urban-rural differences in lifespan variation or the amount of heterogeneity in lifespans *within* rural and urban areas. Lifespan variation is increasingly recognized as a fundamental dimension of health inequality that complements more traditional mortality indicators such as mortality rates and life expectancy (van Raalte et al., 2018). Monitoring lifespan variation is important because it provides information about the level of heterogeneity in the age-at-death distribution within a population as well as the level of uncertainty around the timing of death at the individual-level. In this study, we extend research on the rural mortality penalty by examining urban-rural trends in lifespan variation in the United States over the last three decades.

1.1. Trends in rural mortality

Although mortality rates in the United States have declined steeply since the early 1900s (Bastian, Tejada, and Arias 2020), mortality levels in the US remain an outlier in an international context and lag behind other high-income countries in terms of mortality improvements, age-specific mortality rates, and life expectancy (Ho, 2013; Ho & Hendi, 2018). A primary contributor to the United State's low ranking is greater variability in the average age of death due to premature mortality (Edwards & Tuljapurkar, 2005; Rogers et al., 2020; Vaupel et al., 2011)

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https://doi.org/10.1016/j.ssmph.2022.101213
Received 30 January 2022; Received in revised form 17 July 2022; Accepted 16 August 2022
Available online 22 August 2022

Geographic inequality in life expectancy is growing and appears to be contributing to stagnating mortality improvement in the US as a whole (Fenelon, 2013). These differences are evident at multiple geographic levels but growing urban-rural mortality differences are of particular concern. Several studies have found widening geographic mortality differences within the United States, (Chetty et al., 2016; Farina et al., 2021; Montez et al., 2016; Murray et al., 2006). Such inequalities play an important role in shaping national trends; particularly high mortality rates in the U.S. South and Appalachia appear to be a primary contributor to stagnating mortality improvement for the nation overall (Fenelon 2013; Fenelon & Preston 2012). Several studies in the past decade have investigated widening gaps between rural and urban areas. Research in this area has shown that faster declines in age-adjusted mortality rates in urban areas have culminated in a significant urban-rural mortality penalty beginning in the late 1980s (Cosby et al., 2008, 2019; Cossman et al., 2010; James & Cossman, 2017; Monnat, 2020; Singh & Siahpush, 2014).

For much of U.S. history, living in an urban environment was associated with a greater risk of mortality (Haines, 2001). Before the 1940s, living in an urban environment was not conducive to good health; cities had high population densities conducive to the spread of infection, contaminated water and food supply, and poor municipal sanitation (Cutler & Miller, 2005). In the second half of the 20th century, mortality rates were roughly equivalent until the mid-1980s when metropolitan areas began to outpace their rural counterparts in reducing mortality. In only a few decades, this gradient has led to a substantial urban-rural difference in mortality (Cosby et al., 2008, 2019; James 2014; Singh and Siahpush 2014; Stein et al., 2017). Research examining trends in U. S. life expectancy since 1990 shows that sizeable increases in life expectancy have been found in large central metros while slower improvements, and even declines, have been observed in non-metropolitan areas (Elo et al., 2019). These gains in life expectancy have been particularly notable in White men; White male life expectancy in large central metros increased by 5.09 years between 1990-1992 and 2014–2016 compared to 2.98 years for White women. White women in nonmetropolitan areas increased by only 0.20 years compared to 2.25 years for White men in the same area. Elo et al. (2019) found that this gap persisted across every region of the United States. Although recent research emphasizes increases in midlife mortality (Case & Deaton, 2015, 2017), Elo et al. (2019) found that different age groups contributed to these trends differently depending on their level of rurality. Slowed life expectancy improvements were greater among ages 25–44 than 45–64 in large metropolitan areas and suburbs. However, in small/medium metro and nonmetro areas the situation was reversed as more negative mortality trends were observed for those ages 45–64 than ages 25–44. Although increases in midlife mortality have been emphasized in the literature (Case & Deaton, 2015, 2017), Elo et al. (2019) found that different age groups contributed to these trends differently depending on their level of rurality. Slowed life expectancy improvements were greater among ages 25–44 than 45–64 in large metropolitan areas and suburbs. However, in small/medium metro and nonmetro areas the situation was reversed as more negative mortality trends were observed for those ages 45–64 than ages 25–44.

1.2. The importance of lifespan variation

Monitoring recent trends in mortality rates and life expectancy between urban and rural areas in the United States is important because doing so provides insights into changes in average levels of mortality over time. However, existing studies on rural mortality disparities in the United States are limited by an almost exclusive focus on central longevity indicators such as age-adjusted mortality rates or life expectancy at birth. These studies also typically emphasize differences in life expectancy or mortality rates *between* rural and urban areas. However, lifespan variation, or the extent to which the age at death distribution differs w*ithin* rural and urban areas, has not been investigated. This is an important omission as life expectancy alone provides an incomplete assessment of the mortality profile of a population as it is a poor indicator of the level of variation in the ages at death in a population (Engelman et al., 2010). A comprehensive understanding of the nature of mortality dynamics within a population, especially inequality, requires an account of the changing age distribution of deaths in a population. When life expectancy is increasing over time, averting premature deaths has the effect of compressing the age-at-death distribution, making ages-at-death less variable.

In most high-income, low-mortality nations, there has been a long-term decrease in lifespan variation, though with substantial between-country differences in variation (Canudas-Romo, 2008; Edwards and Tuljapurkar 2005; Smits and Monden 2009). Additionally, international comparison studies show that the United States has higher lifespan variation than other high-income countries, even with similar life expectancies (Aburto et al., 2020; Crimmins et al., 2010; van Raalte et al., 2018; Rogers et al., 2020; Vaupel, Zhang, and van Raalte 2011). These studies suggest that although there is a strong inverse relationship between life expectancy and lifespan variation, the strength of this association is not fixed. In the US, this appears to be due to a greater degree of premature mortality compared to other nations. Some high-income countries have also undergone periods of decompression (Canudas-Romo, 2008; Edwards and Tuljapurkar 2005). Within countries, decompression has been observed for some subgroups (Lynch & Brown, 2001; Lynch et al., 2003). Importantly, most of these studies have examined trends in lifespan variation before recent upticks in working-age mortality which have been more prominent outside of large metropolises. These trends also have the potential to further decouple life expectancy and lifespan variation.

The utility of lifespan variation as a measure of population health is increasingly recognized. Demographers have recently argued that lifespan variation should be measured alongside life expectancy (Canudas-Romo, 2008; Sasson, 2016; van Raalte et al., 2018). There are empirical and theoretical arguments for studying lifespan variation in the context of urban-rural differences in mortality. From an empirical standpoint, shifting cause of death patterns, increasing mortality rates in working-age adults, differential progress in reducing infant deaths, and stagnation in the speed of older age mortality decline all have potential impacts on the level of lifespan variation in urban and rural areas. Documenting higher lifespan variation in rural areas relative to urban areas would expand our understanding of the rural mortality penalty because it reveals an important, but previously overlooked, dimension of the rural mortality penalty; people living in rural areas would not only live fewer years on average but would do so more heterogeneously.

1.3. The present study

Over the past 30 years, rural places have shown slower improvements in mortality rates and life expectancy than urban places, particularly large metropolises. Much has been learned about this gradient but the focus on between-group inequality in prior studies has left another dimension of inequality unexplored. Does the rural mortality penalty in life expectancy extend to lifespan variation? To address this question, we examine urban-rural trends in life expectancy and lifespan variation in the United States between 1990 and 2017. This period has been widely documented as the key period of divergence in urban-rural mortality trends (Cosby et al., 2008; Elo et al., 2019; Monnat, 2020; Vierboom et al., 2019). This analysis provides evidence as to whether lifespans in rural and urban areas have become less variable (compression), more variable (dispersion), stayed the same due to a lack of change in life expectancy, or stayed the same despite increases in life expectancy (shifting). We also investigate the importance of age-specific mortality trends (including recent increases in working-age mortality) to changes in life expectancy and lifespan variation in urban and rural areas. To that end, this study addresses the following questions: 1) To what extent has life expectancy and lifespan variation in rural and urban

areas in the United States changed between 1990 and 2017? 2) What are the age-specific contributions to changes in life expectancy and lifespan variation in rural and urban areas?

2. Methods

2.1. Data

The analyses draw on multiple data sources. Age-specific death rates were calculated for each year between 1990 and 2017 for urban and rural areas. Numerator data are from restricted-use Multiple Cause of Death (MCD) files obtained via special request from the U.S. National Center for Health Statistics (NCHS). For population counts (person-years of exposure), we used single-year of age mid-year population estimates from the Survey of Epidemiology and End Results (SEER) for the years 1990–2017. SEER data are based on U.S. Census bridged-race population estimates and are adjusted to account for large population changes in Alabama, Mississippi, Louisiana, and Texas counties affected by Hurricanes Katrina and Rita.

To situate the urban-rural patterns within a broader context, we also compare e_0 and $e_0^\dagger$ in urban and rural areas with the United States overall and a high-income country aggregate. These data were taken from the Human Mortality Database (HMD) and include deaths from Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Italy, Japan, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, and the United Kingdom. Our inclusion of these countries was based on a previous study of trends in life expectancy in high-income countries (Ho & Hendi, 2018).

All analyses are restricted to the 1990–2017 period. This was done for two reasons. First, prior research shows that urban-rural mortality rates first started to diverge around 1990 urban-rural mortality disparities in the United States started to emerge (Elo et al., 2019; Monnat 2020; Vierboom et al., 2019). The county-level population data needed to calculate age-specific occurrence-exposure rates are not readily available before 1990.

Using each of these data sources, age-specific occurrence-exposure death rates were calculated for each level of the NCHS Urban-Rural Classification Scheme for Counties. Because single-year-of-age population estimates are not currently available at the county level above age 85, death rates were smoothed by fitting a Kannisto model (Thatcher et al., 1998) over ages 75 to 84 and extrapolating from ages 85 to 110. This approach has been used in previous studies on lifespan variation (Sasson, 2016; van Raalte et al., 2018) and life expectancy more generally (Elo et al., 2019).

2.2. Rurality

Deaths were classified based on decedents' county of residence using the National Center for Health Statistic's 2013 Urban-Rural classification scheme for counties (Ingram & Franco, 2014). Counties were classified into one of six categories including four metropolitan categories (large central metro, large fringe metro, medium metro, and small metro) and two nonmetropolitan categories (micropolitan and noncore). The NCHS scheme is used widely in health research. Unlike other schemes such as Rural-Urban Continuum Codes (RUCC) and Urban Influence Codes (UIC), the NCHS scheme differentiates central and suburban counties within large MSAs. This is important because large central metros and their suburbs differ on several important health indicators such as health behaviors, self-rated health, and mortality (Ingram & Franco, 2014). Although many studies examining urban-rural differences in health and mortality use RUCC codes (Cosby et al., 2008; James, 2014; James & Cossman, 2017; Monnat, 2020), they potentially miss important differences between large fringe metros and other areas. Consistent with other studies using the NCHS urban-rural classification scheme (Elo et al., 2019; Stein et al., 2017; Vierboom et al., 2019), we applied the 2013 scheme to all periods.

2.3. Lifespan variation

Several measures have been developed to assess lifespan variation. Although these measures differ somewhat in their formal properties, conceptually they all measure the amount of heterogeneity in lifespan within a population. Sensitivity analyses of lifespan variation measures have shown that they are highly correlated (van Raalte & Caswell, 2013; Vaupel et al., 2011; Vaupel & Canudas-Romo, 2003). In this study, life disparity ($e_0^\dagger$) was used as the measure of lifespan variation. We chose this measure for two primary reasons. First, it has an intuitive interpretation; it represents how much lifespans differ among individuals in a given population. Second, it is decomposable; using this measure allowed us to examine age contributions to trends in lifespan variation in rural and urban areas.

Life disparity is the average remaining life expectancy at the age of death, or the life years lost to death (Vaupel & Romo, 2003). A population with perfect equality in lifespans would have a life disparity of zero with no premature deaths. Lower life disparity represents a population with lower variation in lifespan and higher life disparity represents a population with higher variation in lifespan. Life disparity is calculated as the average years of remaining life expectancy at each age, weighted by the number of life table deaths at each age (Vaupel & Romo, 2003). Consistent with previous research using life disparity, our analyses will report life disparity at age zero $e_0^\dagger$. This calculation can be expressed as:

$$e_0^\dagger = \frac{\int_0^\omega d(x)e(x)dx}{l(0)},$$

where $d(x)$ is the number of life table deaths at age x, ω is the open age interval (i.e., 110+ in our case), $e(x)$ is the remaining life expectancy at age x, and $l(0)$ is the number of survivors at age zero (i.e., the life table radix). An important attribute of $e_0^\dagger$ is the threshold age which is the age separating premature and late mortality in any given population. Reductions in life disparity are driven by averting premature deaths (i.e., those below the threshold age). Whereas age-specific mortality improvements always have the effect of increasing life expectancy, Zhang and Vaupel (2009) have demonstrated that mortality improvements above the threshold age, which is typically just below life expectancy at birth, increase variation.

2.4. Analysis

We examine trends in life expectancy and lifespan variation from 1990 to 2017 by metropolitan status. As a first step, the number of life table deaths at each age was tabulated for 1990 and 2017 by metropolitan status and each NCHS region to document how the age-at-death distribution differed at the beginning (1990) and end of the study period (2017). Next, we tabulated trends in life expectancy at birth (e_0) and life disparity at birth $\left(e_0^\dagger\right)$ across single-year period intervals to examine how these outcomes have changed from 1990 to 2017. Supplementary Joinpoint regression analyses were conducted using the National Cancer Institute's Joinpoint Regression Program to identify years where trends in life expectancy and life disparity changed significantly (i.e., joins) and to assess the significance of linear segments between joins (Kim, et al., 2000). This tested a maximum of 5 joins using a Monte Carlo Permutation test. The results of these models are included in Appendix A.

Finally, we decomposed period differences in life expectancy at birth and life disparity at birth by age using a stepwise replacement algorithm (Andreev et al., 2002). This algorithm is designed to decompose differences between aggregate measures computed from life tables and has been adapted to decompose lifespan inequality (Andreev & Shkolnikov, 2012; Shkolnikov et al., 2001, 2011).

3. Results

3.1. Trends in life expectancy

These results describe trends in life expectancy and life disparity from 1990 to 2017 by NCHS classification. First, we show trends in life expectancy at birth for both sexes for each NCHS urban-rural classification between 1990 and 2017 (Fig. 1). Consistent with previous work examining changes in urban-rural mortality differences beginning in the 1990s (Cosby et al., 2008; Elo et al., 2019; Monnat 2020; Vierboom et al., 2019), greater increases in the rate of mortality improvement in more urban areas have led to a substantial gap in life expectancy between metropolitan and nonmetropolitan areas. Nonmetros have shown relatively slow improvement whereas metros have shown marked improvement over much of this period. However, this figure also shows important heterogeneity within the broader metropolitan and nonmetropolitan classifications. From 1990 to 2017, large central metros had the greatest increase in life expectancy (5.4 years) which led to a similar life expectancy as large fringe metros by the second half of the 2010s. Supplementary joinpoint regression analyses show that statistically significant increases in large central metro life expectancy occurred between 1994 and 2010, with the largest increase occurring from 1994 to 1997 (See Appendix A).

Medium and small metro areas had similar levels of life expectancy for much of the period under observation but maintained slightly higher life expectancy beginning in the 2000s. The two nonmetropolitan areas (noncore and micropolitan) had similar trends in life expectancy from 1990 to 2017 with a slightly higher life expectancy in micropolitan areas than noncore in each year. Fig. 1 also reveals stagnating improvements in life expectancy in all areas during the 2010s. Notably, modest reversals were beginning after 2011 for all areas except large central metros and their suburbs. Joinpoint regression models show that the declines in life expectancy in the 2010s were only statistically significant for micropolitan and noncore populations beginning in 2011 and 2012, respectively.

Fig. 1 also includes a comparison of NCHS classifications to the United States as a whole as well as 17 high-income countries (exclusive of the United States). This comparison clearly shows that the United States has failed to keep pace with life expectancy improvements in other high come countries but also that the geographic differences observed in the United States play an important role in the growing gap between the United States and other high-income countries. In fact, in 2017 the difference between the United States and other high-income countries (3.8 years) is similar in magnitude to the difference between large central metros and noncore places (3.5 years).

3.2. Changes in the age-at-death distribution by metropolitan status

Next, as a preliminary examination of potential changes in lifespan variation during this same period, we plotted the density of life table deaths by NCHS classification in 1990 and 2017 (Fig. 2). This allows for a visualization of the distribution of life table deaths at each age for each population as well as how this distribution differs between 1990 and 2017. A wider distribution indicates more inequality in the age-at-death and a narrower distribution indicates less inequality in the age-at-death. The distribution of life table deaths in nonmetropolitan areas has had only a slight rightward shift (increase in modal age at death) and very little change in the shape of the distribution of life table deaths. In contrast, the distribution of deaths in metropolitan areas shifted rightward toward older ages and become increasingly compressed around a rising late-life modal age at death. This figure implies that mortality compression occurred in metropolitan areas, particularly large central and fringe metros.

3.3. Trends in lifespan variation

Visual inspection of age-at-death distributions is a useful first step in understanding the amount of lifespan variation in a population, but quantification is needed to make more precise comparisons. To quantify changes in lifespan variation, Fig. 3 shows trends in lifespan variation from 1990 to 2017 as measured by life disparity at birth ($e_0^\dagger$). This figure shows that greater decreases in life disparity have occurred in metropolitan areas compared to nonmetropolitan areas resulting in a metro-nonmetro gap in life disparity. Similar to trends in life expectancy from 1990 to 2017, large central metros had the largest improvement in life disparity during this period declining from 13.9 in 1990 to 12.5 in 2017. Most of the improvement in large central metro life disparity occurred in the 1990s, a period when life expectancy also showed the greatest improvement. Joinpoint analyses showed that large central metros had statistically significant decreases in variation beginning in

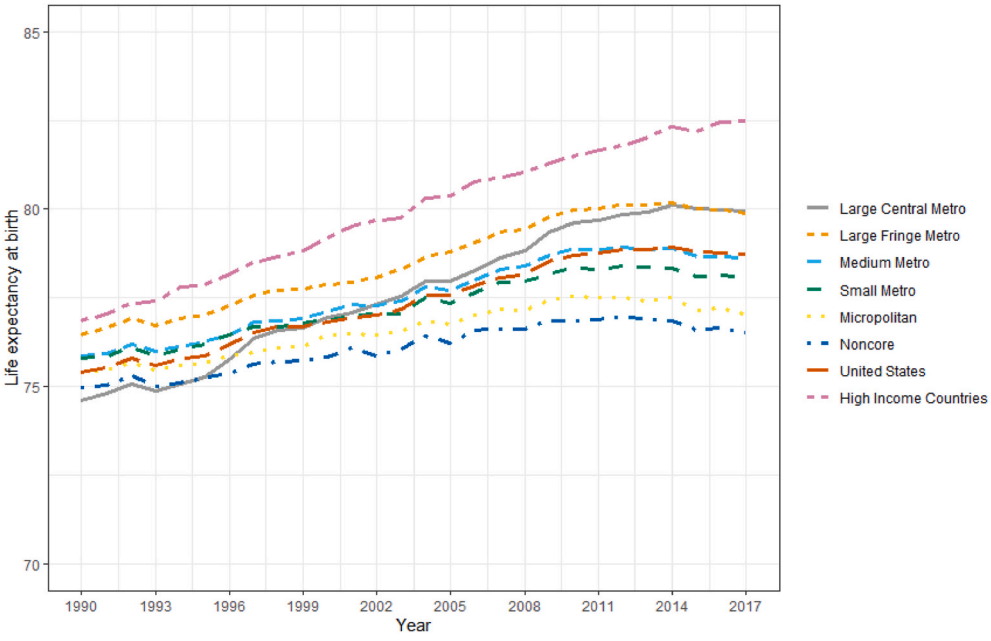

Fig. 1. Trends in life expectancy by urbanization level and for the United States and high income countries, 1990–2017.

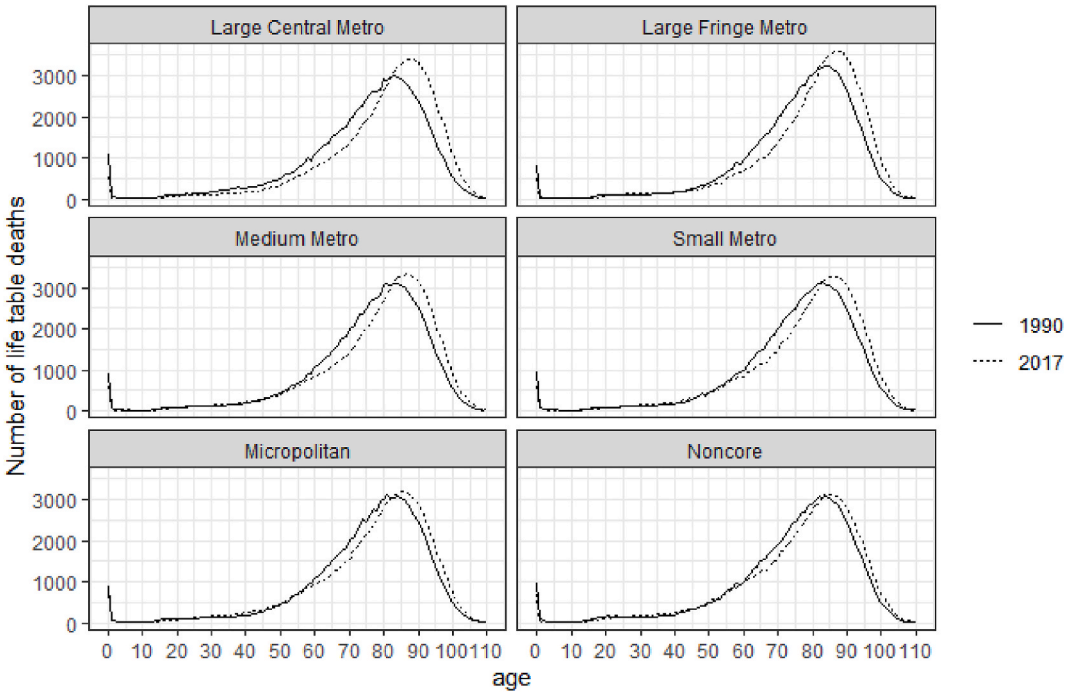

Fig. 2. Density of life table deaths (dx) by age in the United States in 1990 and 2017 by urbanization level.

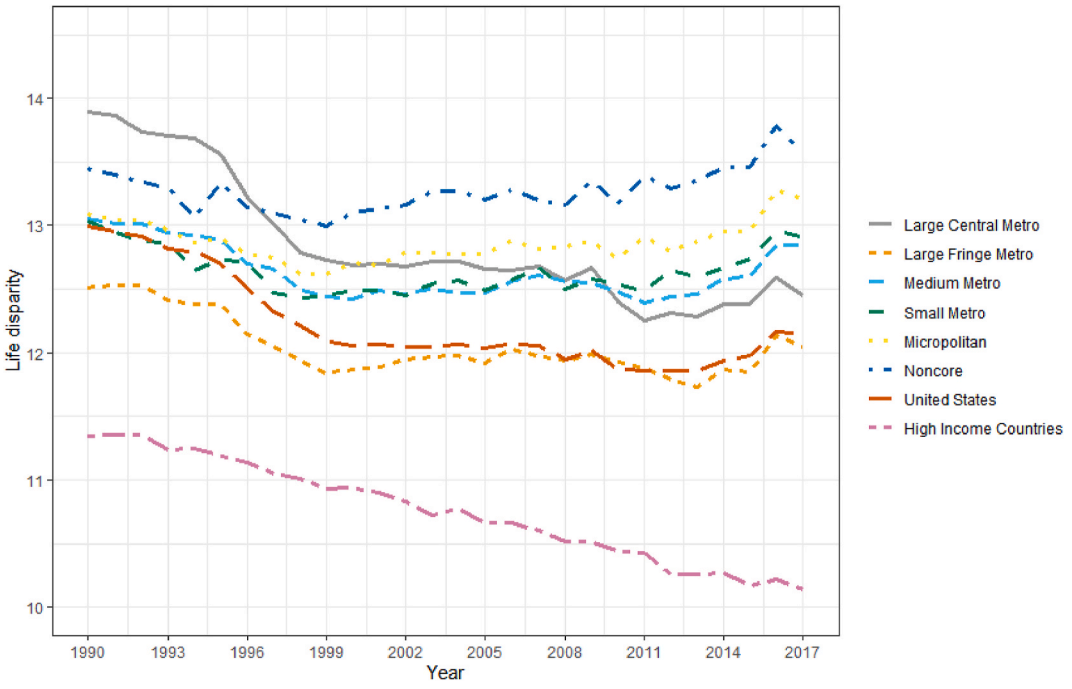

Fig. 3. Trends in life disparity by urbanization level and for the United States and high-income countries, 1990–2017.

1990 and ending in 1998.

Despite recent increases, levels of life disparity remain well below their 1990 levels in large central and fringe metros. However, less densely populated metros (small and medium) have nearly returned to their 1990 levels of life disparity, despite small but sustained improvements in life expectancy at birth. During this period, the most rural places (noncore) have shown an overall increase in life disparity despite experiencing small decreases in variation in the 1990s. Taken together, these results provide evidence that since 1990, mortality has compressed in large central and fringe metros. In medium and small metropolitan areas, improvements in both life expectancy and life disparity have been more modest. In nonmetro areas, life disparity has remained consistently high and is showing recent signs of decompression. There is also evidence of significantly rising life disparity in all areas, including large central metros. While life expectancy appeared to be merely stagnating in large central metros, life disparity is rising in the most recent periods.

Comparing trends in life disparity to other income countries reinforces that the United States is on a very different trajectory. The United States has shown a more modest decline in life disparity from

1990 to 2017 compared to other high-income countries. As a result, the already gap in life disparity between the United States and other high-income countries has grown substantially since 1990. This is particularly true for the most rural places (i.e., noncore) in the United States which had 3.6 additional years of average life lost compared to the high-income countries.

Fig. 4 shows the relationship between life expectancy at birth and life disparity at birth from 1990 to 2017 by NCHS Classification. This figure clearly shows a decoupling of life expectancy and life disparity in nonmetropolitan areas (micropolitan and noncore) but shows that this has been particularly true in most rural places (noncore). There is no correlation between life expectancy and life disparity in micropolitan areas and there is a positive correlation between life expectancy and life disparity in noncore areas ($r = 0.27$). In metropolitan areas, the association between life expectancy and life disparity was strongest in large fringe metros ($r = -0.73$) and large central metros ($r = -0.92$). The association was weaker in medium ($r = -0.63$) and small metros ($r = -0.28$), however, these areas also experienced smaller increases in life expectancy during this period. Collectively, these associations highlight the importance of examining both life expectancy and life disparity. Life expectancy and life disparity in any given year are correlated strongly in large central and fringe metros. However, in nonmetropolitan areas, life disparity is increasing without a corresponding decrease in life expectancy. This worrisome trend is less apparent when examining life expectancy.

3.4. Age decomposition of changes in life expectancy and lifespan variation

Table 1 shows age-specific components of change in life expectancy at birth from 1990 to 2017 (top panel) and 2008 to 2017 (bottom panel) across levels of urbanization. Single-year of age contributions are shown in Appendix B. These periods were examined to understand age-specific contributions to mortality changes observed over the entire study period (1990–2017) and the period when life expectancy gains began to stagnate and eventually decline (2008–2017). The first column in Table 1 shows the absolute change in years of life expectancy at birth within each respective period. The remaining columns show the number of years each respective age group contributed to the absolute change in life expectancy at birth. The age group-specific results are additive so that summing columns 2–6 equals the total in the first column within panels. Positive values reflect decreases in age-specific mortality resulting in increased life expectancy at birth. Negative values reflect increases in age-specific mortality resulting in decreased life expectancy at birth.

Table 1 (top panel) shows that in all areas except large central metros mortality increased among the 25–44 age group between 1990 and 2017. These increases in premature mortality curtailed life expectancy gains over the period. Mortality rates declined between 1990 and 2017 among every other age group examined with the steepest reductions occurring among the 45–64 and 65–84 age groups. Large central metros were the only area that experienced mortality reductions among all the age groups examined between 1990 and 2017. These broad improvements in mortality contributed to life expectancy gains within large central metros over the period. Table 1 (bottom panel) also shows age contributions to changes in life expectancy at birth between 2008 and 2017. In this latter period, mortality increased in all areas among the 25–44 age group. Aside from large central and fringe metros, mortality increased in the 45–64 age group in all other areas, particularly micropolitan and noncore areas. Life expectancy at birth decreased in micropolitan and noncore areas and these changes were driven primarily by increased mortality among persons ages 25–44 and 45–64.

Table 2 shows age-specific components of change in life disparity at birth across urban and rural areas. Single-year of age contributions are shown in Appendix B. This table is interpreted the same as Table 1 except that the first column shows the absolute change in years of life disparity rather than life expectancy. The remaining columns in each of these panels show the number of years contributed to the total change in life disparity for each age group, summing to the total contribution shown in the first column. From 1990 to 2017, large central metros had the largest decrease in life disparity. In this table, positive contributions reflect age-specific mortality rate increases that contribute to increases in life disparity whereas negative contributions reflect mortality rate decreases that contribute to decreases in life disparity. In all NCHS classifications, the age groups 65–84 and 85 and above include ages greater than the threshold age (just below life expectancy), and therefore mortality improvements at ages greater than the threshold age are associated with increased life disparity.

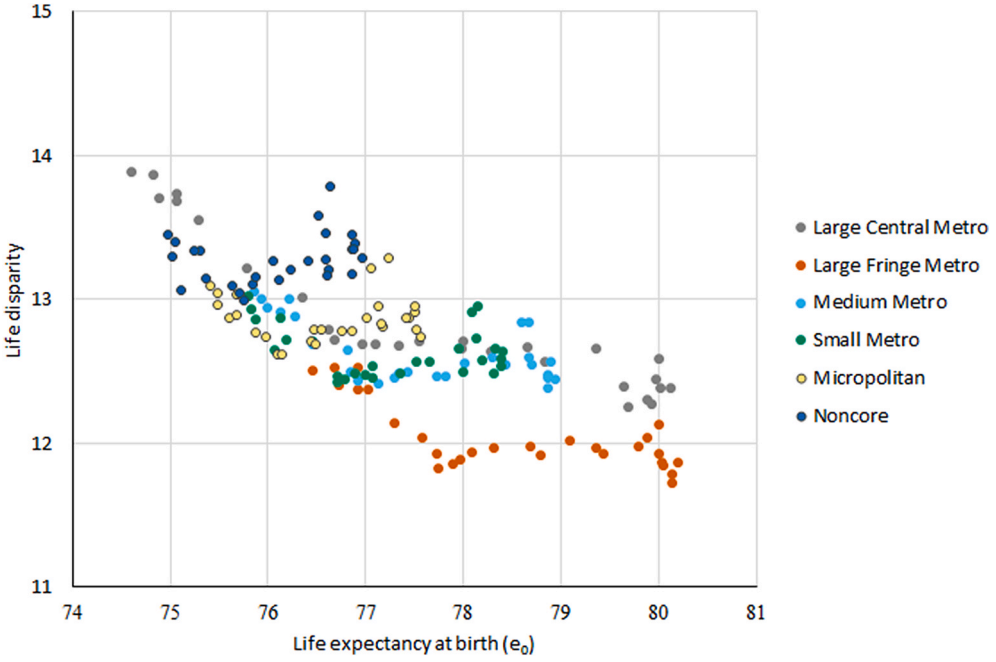

Fig. 4. Life expectancy and life disparity in the United States by urbanization level, 1990 to 2017.

Table 1
Age group contributions to changes in life expectancy at birth in the united States Between 1990 to 2017 and 2008 to 2017 by urbanization level.

	1990–2017						
	Δe0	<1 year	1–24 years	25–44 years	45–64 years	65–84 years	85+ years
Large central metro	5.36	0.43	0.38	0.76	1.34	2.09	0.36
Large fringe metro	3.43	0.24	0.20	−0.11	0.89	1.89	0.32
Medium metro	2.74	0.24	0.23	−0.13	0.51	1.63	0.26
Small metro	2.29	0.26	0.23	−0.26	0.38	1.48	0.21
Micropolitan	1.64	0.21	0.26	−0.35	0.16	1.18	0.19
Noncore	1.53	0.20	0.34	−0.37	0.13	1.02	0.21
	2008–2017						
	Δe0	<1 year	1–24 years	25–44 years	45–64 years	65–84 years	85+ years
Large central metro	1.14	0.12	0.04	−0.06	0.29	0.59	0.16
Large fringe metro	0.44	0.07	0.01	−0.31	0.10	0.51	0.07
Medium metro	0.18	0.07	0.01	−0.28	−0.07	0.36	0.10
Small metro	0.09	0.08	0.01	−0.27	−0.16	0.30	0.14
Micropolitan	−0.11	0.04	0.03	−0.28	−0.25	0.27	0.08
Noncore	−0.10	0.02	0.10	−0.25	−0.25	0.16	0.12

Note. Δe0 represents the total or absolute change in life expectancy at birth over time within each respective period. Positive values represent a net increase in life expectancy at birth due to decreased mortality rates. Negative values represent a net decrease in life expectancy at birth due to increased mortality rates. Age group-specific values sum to the total change within each period (Δe0).

Table 2
Age group contributions to changes in life disparity at birth in the United States Between 1990 to 2017 and 2008 to 2017 by urbanization level.

	1990–2017						
	$\Delta e_0^\dagger$	<1 year	1–24 years	25–44 years	45–64 years	65–84 years	85+ years
Large central metro	−1.44	−0.36	−0.30	−0.53	−0.66	−0.01	0.41
Large fringe metro	−0.47	−0.21	−0.17	0.09	−0.45	−0.10	0.37
Medium metro	−0.21	−0.20	−0.18	0.10	−0.23	0.01	0.30
Small metro	−0.11	−0.22	−0.19	0.18	−0.16	0.02	0.24
Micropolitan	0.12	−0.17	−0.21	0.24	−0.05	0.06	0.25
Noncore	0.14	−0.17	−0.26	0.25	−0.04	0.06	0.30
	2008–2017						
	$\Delta e_0^\dagger$	<1 year	1–24 years	25–44 years	45–64 years	65–84 years	85+ years
Large central metro	−0.12	−0.10	−0.03	0.05	−0.17	−0.04	0.18
Large fringe metro	0.11	−0.06	−0.01	0.24	−0.06	−0.05	0.05
Medium metro	0.29	−0.06	−0.01	0.21	0.03	0.00	0.11
Small metro	0.42	−0.07	0.00	0.20	0.08	0.01	0.20
Micropolitan	0.38	−0.04	−0.02	0.20	0.12	0.01	0.11
Noncore	0.42	−0.01	−0.08	0.18	0.12	0.02	0.19

Note: $\Delta e_0^\dagger$represents the total or absolute change in life disparity over time within each respective period. Positive values reflect net increases in life disparity over time due to increased mortality. Negative values reflect net decreases in life disparity over time due to decreased mortality. Mortality rate improvements above the threshold age (approximately life expectancy at birth) increase life disparity and vice versa. Age group-specific values sum to the total change within each period.

Large central metros experienced the greatest decline in life disparity at birth from 1990 to 2017. Mortality improvements among persons ages 45–64 and ages 25–44, respectively, primarily contributed to these declines. However, improvements in infant mortality had an outsized influence on declining life disparity in large central metros and had the greatest single age contribution to the decrease in life disparity from 1990 to 2017. Outside of large central metros, decreasing life disparity in metropolitan areas was driven mostly by improvements in infant mortality and midlife mortality (ages 45–64). All regions had mortality improvements in old-age mortality that were associated with positive contributions to life disparity due to this age group being above the threshold age. However, for all metropolitan areas, this increase was more than balanced out by improvements in other age groups.

Nonmetropolitan areas did not show sustained improvements in life disparity from 1990 to 2017. Although there were some improvements in the 1990s, micropolitan areas had higher life disparity in 2017 compared to 1990. This was driven largely by mortality increases among 25–44-year-olds as well as mortality decreases above the threshold age. Also, compared to metropolitan areas, micropolitan and noncore areas had much smaller improvements in infant mortality and midlife mortality.

The bottom panel of Table 2 shows age-specific components of change in life disparity at birth from 2008 to 2017. During this period of stagnating mortality improvement and decline, large central metros were the only metropolitan area that showed improvement in life disparity, though this increase was much smaller than what was observed for the entire period of 1990–2017. Outside of large central metros, increases in life disparity were driven largely by mortality increases at ages 25–44. In nonmetropolitan areas increases in life disparity were also driven by mortality increases at ages 45–64, though to a lesser extent than those at ages 25–44.

4. Discussion

Although several studies have documented a growing rural mortality penalty, all of these studies have focused on average differences in mortality between urban and rural populations. An equally important yet unexamined aspect of the rural mortality penalty is the difference in

lifespan variation among individuals in rural and urban populations. This study expands this literature by documenting trends in lifespan variation from 1990 to 2017, the key period of divergence in mortality trends between rural and urban places.

The United States states has had slower improvements in mortality than other high income countries. Yet rural populations are being left even further behind. Our analyses demonstrate that the urban-rural mortality gap widened primarily due to mortality improvements in metropolitan areas and stagnating, or even declining, mortality improvements in rural areas. From 1990 to 2017, metropolitan areas gained 3.9 years in life expectancy at birth compared to 0.6 years in nonmetropolitan areas. These improvements are noticeably larger than the United States as whole during this period. This finding is consistent with previous work on the rural mortality penalty. However, the results in this study expand previous work by highlighting the importance of mortality improvements in large central metros in driving the rural mortality penalty. These areas underwent a drastic turnaround in their mortality profile during this period, starting with the lowest life expectancy and ending with the highest. In contrast, the suburbs of large central metros have maintained a high ranking in mortality throughout this period, a point which is underappreciated in the literature as many existing studies use RUCC codes that do not identify large fringe metros. After 2008, there have also been significant decreases in life expectancy in nonmetro areas due to increases in working-age mortality, further exacerbating the rural mortality penalty.

The analyses in this study also demonstrate that there is an additional dimension of heterogeneity in the urban-rural mortality gap that we should be paying attention to. Specifically, the improvement in metropolitan life expectancy from 1990 to 2017 has been accompanied by a compression of mortality 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 means that lifespans have become longer and less variable in metropolitan areas compared to nonmetropolitan areas. This development has been more apparent in large central metros and their suburbs. In contrast, nonmetropolitan areas have not had any sustained improvement in lifespan variation despite modest improvements in life expectancy at birth.

These results also clearly demonstrate that lifespan variation provides unique information about the mortality profile of metropolitan and nonmetropolitan areas. The correlation between life expectancy and lifespan variation differed across urban and rural areas. In metropolitan areas, especially large central metros and their suburbs, the measures were strongly negatively correlated. However, these measures were not at all correlated in micropolitan areas and were positively correlated in rural areas. Substantively, this means that life expectancy at birth should not be used as a proxy for the amount of inequality of life spans in a population nor should a higher or lower life expectancy necessarily be assumed to equate to higher or lower inequality. Lifespan variation is also more sensitive to increases in premature mortality than life expectancy and can therefore detect adverse trends earlier than life expectancy (Vigezzi et al., 2021). In this study, analyses of life expectancy in large central metros suggest that life expectancy improvements had begun to level off and then decline slightly starting in 2011. However, this decline was not statistically significant. Yet, assessing lifespan variation showed that the situation in large central metros was more troubling than would be expected by examining life expectancy alone as increases in lifespan variation were statistically significant beginning in 2011. This development if it continues has the potential to threaten gains made in large central metros from 1990 to 2010.

The age decomposition results in this study provide some additional clues into why nonmetropolitan areas have lagged their metropolitan counterparts in improving life expectancy and lifespan variation. Many studies, particularly early ones, on urban-rural mortality disparities in the United States primarily examine trends in age-adjusted mortality rates. Consequently, these studies fail to capture important changes in age-specific mortality between urban and rural places. Our results suggest that changes in age-specific mortality patterns between urban and rural areas played a crucial role in widening urban-rural mortality disparities. The largest contributor to the rural mortality penalty in terms of life expectancy was improvements in older age mortality (ages 65 to 84). Because of the so-called "threshold age," the age at which mortality improvements contribute to greater lifespan variation, the mortality improvements shown by this age group contributed negatively to lifespan variation, overall. Instead, the gap in lifespan variation was driven primarily by improvements in young adult (25–44) and midlife (45–64) mortality which is consistent with prior research on life expectancy (Elo et al., 2019; Vierboom et al., 2019). These increases in mortality among working-age adults have led to a decoupling of life expectancy and lifespan variation in nonmetropolitan areas. Consequently, nonmetropolitan areas generally displayed more favorable trends when examing life expectancy as opposed to lifespan variation. Assessing only life expectancy would have provided an incomplete profile of mortality in metropolitan and nonmetropolitan areas.

Age decomposition also revealed that reductions in infant mortality were a key reason that life expectancy and lifespan variation improved in metropolitan areas. This was the case, particularly in large central metros which experienced dramatic gains in life expectancy and alongside equally dramatic reductions in lifespan variability over the period examined. In fact, as a single year of age, improvements in infant mortality undoubtedly had an outsized influence on mortality improvement. The outsized role that infant mortality played in shaping urban-rural mortality gradients is not surprising because preventing premature deaths is critical for increasing life expectancy and reducing lifespan disparity. Yet, the importance of infant mortality seems to be underappreciated in discussions of the rural mortality penalty. Instead, the current discourse seems to bias recent increases in midlife mortality among non-Hispanic Whites who have been most affected by "deaths of despair."

4.1. Limitations and future directions

Our results have several potential limitations. There are two limitations related to the urban-rural measure used in this study. First, the NCHS scheme is only one of a few that are used in the rural health disparities literature. Although the NCHS scheme has the benefit of differentiating large central metros from their suburbs, it does not have as many nonmetropolitan classification codes as the RUCC scheme. Using the RUCC scheme would have had the disadvantage of requiring the pooling of 5-year period intervals to prevent small cell sizes without the advantage of identifying large fringe metros. However, we also recognize that the utility of RUCC codes may be more apparent in different analytic scenarios. For example, when combined with other geographic units such as United States Census regions, there are some notable differences among nonmetropolitan RUCC classifications (Monnat, 2020).

Second, we applied the 2013 NCHS scheme to the entire period range in the study. This means that we will have failed to capture county shifts in classification during this period as the scheme ultimately reflects counties' classifications as of the release of the 2013 scheme (latest available). Although an earlier scheme released in 2006 is available, the 1990 NCHS scheme used a different methodology that is not comparable. However, most studies using the NCHS urban-rural classification scheme have applied one scheme across the period of interest (Elo et al., 2019; Stein et al., 2017; Vierboom et al., 2019). Vierboom et al. (2019) did not find differences in results depending on whether counties were assigned based on their 2013 scheme or the scheme that was in place at the time. This suggests that the substantive conclusions of my study would not have changed if I used a different strategy for the classification of counties. Additionally, our sensitivity analysis showed similar results when limiting the analysis to counties who did not change classification over the study period. Regardless, the potential impact of

changing classifications remains a limitation on the level of precision that this study provides.

Our analysis starts in 1990 due to the availability of single-year of age denominator data by county. Although the rural mortality penalty is often described as beginning in the 1990s, this may depend on which type of urban area is being compared. Studies that have examined mortality by the level of urbanization before 1990 have not used the NCHS scheme, which is unique in allowing for the separation of large central and large fringe metros. Before 1990, there may have been a mortality disadvantage in large central metros due to higher rates of HIV/AIDS mortality. Elo et al. (2019) showed that a large portion (nearly 1 year) of the increases in non-Hispanic White life expectancy in large central metros from 1990 to 1992 to 2014–2016 was due to reductions in deaths due to HIV/AIDS. Further, there may have been a disparity between rural places and large fringe metros that began earlier, which would have been obscured in previous studies that look at aggregate metro-nonmetro differences in mortality. Future studies should consider including an earlier pre-1980s baseline when examining mortality trends in large central metros. While the use of single-year-of-age data in our study was preferable given that our analysis focused on calculations of life disparity at birth $\left(e_0^{\dagger}\right)$. This limitation would not be true for studies focusing on life expectancy where abridged life tables would be appropriate.

Our study did not account for potential compositional differences in social and demographic characteristics between rural and urban areas. Poverty status has been shown to moderate the effects of rurality on mortality risk in that the rural mortality penalty is present to a lesser degree in low-poverty rural counties compared to high-poverty rural counties (Cosby et al., 2019). However, this effect does not entirely account for the rural mortality penalty in the aggregate. Despite the popular narrative, rural people are not poorer on average in many places across the US; Census data shows that poverty rates are lower for those living in rural areas in every Census region and rural households had higher median incomes than urban households in 32 US states (Bishaw & Posey, 2016; Elo et al., 2019). Selective migration has been shown to have an impact on mortality differences between rural and urban areas (Cosby et al., 2019; Elo et al., 2019). The in-migration of the working-age population in large central metros and their suburbs appears to be strongly positively correlated with improvements in life expectancy in these areas. These same in-migrations have not occurred to the same extent in small and medium metros (where life expectancy gains are more modest) and have declined nonmetros (where life expectancy gains are small). How these compositional shifts may have impacted lifespan variation was not examined in this study. However, given the correlation between life expectancy and lifespan variation in large central and fringe metros, it can be reasonably inferred that these shifts would have been associated with the decreased lifespan variation observed in this study. Future research should investigate the specific effects of these migrations on age-related mortality risk and its impacts on geographical differences in lifespan variation.

Our study did not examine geographic differences by race and ethnicity. Few studies have systematically examined the intersection of race and geography so little is known about a race-specific rural mortality penalty. Research examining Black-White mortality differences at the national level is a useful starting point and clearly shows that racism and its attendant structural, cultural, and individual manifestations have created a significant mortality penalty for Black Americans (Hayward et al., 2000; Phelan & Link, 2015; Williams, 2012; Williams et al., 2019). Studies specifically examining the intersection of race and rurality are additive rather than interactive; Whites and Blacks both suffer a rural mortality penalty compared to their non-rural counterparts (James & Cossman, 2017; Probst et al., 2020). However, studies have shown that improvements in large central metropolitan areas play an outsized role in the development of the rural mortality penalty (Elo et al., 2019; Vierboom et al., 2019). Whether this is also the case for Black Americans is not known as these studies focused on non-Hispanic Whites. Previous research suggests that increased political fragmentation and residential segregation in metropolitan areas may have led to increases in Black-White mortality disparities (Deaton & Lubotsky, 2003; Do et al., 2017; Hutson et al., 2012; Iceland & Wilkes, 2006; Kim & Bruckner, 2016). Future research should prioritize the inclusion of non-White populations and examine the extent to which the large-central turnaround in mortality is true for all subgroups.

4.2. Implications

The degree of uncertainty around the timing of death has costly impacts on economic behavior related to savings and retirement behavior (Edwards 2013; Edwards and Tuljapurkar 2005). Individuals' subjective survival assessments also have potential impacts on how they plan their life course (Hurd and McGarry 1995; van Raalte et al., 2018). At the population level, measuring lifespan variation provides information that has important implications for how we monitor population health, forecast insurance and annuity markets, structure pension schemes, and support public health care plans (van Raalte et al., 2018). For example, increases in lifespan variation can indicate reductions in the speed of mortality decline at older ages or increases in early or mid-life mortality (Aburto et al., 2020; van Raalte et al., 2018; Vaupel et al., 2011).

Ideally, we would like the United States to move towards a society that maximizes how long people are living and the share of those years that are lived in good health. However, doing so in a way that maximizes equality may require a difficult evaluation of policy priorities. As Vaupel et al. (2011) have pointed out, to improve lifespan variation, policies should focus on reducing premature mortality. Diverting funding and attention away from expensive treatments for extending the life of the elderly populations would potentially allow for additional resources to be put towards premature mortality (Heath, 2010; Vaupel et al., 2011). Such strategies would also have a larger impact on increasing life expectancy. Rural areas have had less progress in reducing premature mortality than urban areas. As shown in previous studies (Cossman et al., 2010; Elo et al., 2019; Monnat, 2020; Vierboom et al., 2019), the causes of death responsible for the rural mortality penalty have largely been preventable. Therefore, policymakers who are serious about reducing lifespan inequality should take a multifaceted approach that targets preventable causes of premature mortality.

The results of our study also have methodological implications with policy relevance. Van Raalte et al. (2018) have made a compelling argument that lifespan variation should be measured alongside life expectancy. They demonstrate that measures of average levels of mortality can obscure substantial levels of variation. In the case of the United States, the correlation between the two measures is not as strong as in other wealthy nations due to the persistently high infant mortality, within-population inequality, and emerging midlife mortality crisis. This also proved to be the case in the current study Where life expectancy appeared to be merely stagnating or slowly reversing, lifespan variation was rising. Hopefully, these results make a compelling case that monitoring lifespan variation adds additional benefits above and beyond measuring life expectancy alone. These should not be restricted to academic researchers but those administrative bodies that monitor population health. Given that most measures of life expectancy are a simple extension of the life table, organizations such as the National Center for Health Statistics which routinely monitors and reports life expectancy could easily expand their reporting to include lifespan variation. A similar transition was made to studying income inequality via routine monitoring of Gini coefficients long ago. There is no reason the same cannot be true of lifespan inequality.

4.3. Conclusion

Despite these limitations, our study shows that the greater pace of

mortality improvement in metropolitan areas, especially large central metros and their suburbs, has been accompanied by a compression of mortality. This compression of mortality has resulted in lower levels of lifespan variation in urban areas compared to rural areas. This represents an additional dimension of inequality for people living in rural areas; those living in rural areas not only live shorter lives but do so with less predictability and greater heterogeneity than those in urban areas.

Credit statement

Benjamin Walker: Conceptualization, methodology, data curation, writing-original draft, investigation, visualization. **Dustin Brown:** Conceptualization, supervision, writing-review & editing.

Author statement

This manuscript has not been accepted or published previously and is not being considered for publication elsewhere. Both authors contributed substantially to the writing and editing of the manuscript, approve of the submission of the paper to the journal, and agree that the accepted manuscript will not be published elsewhere. Each author declares that there are no competing interests to disclose.

Declaration of competing interest

None.

Data availability

The data that has been used is confidential.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ssmph.2022.101213.

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