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The where of when: Geographic variation in the timing of recent increases in US county-level heart disease death rates

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Abstract

Purpose: Within the context of local increases in US heart disease death rates, we estimated when increasing heart disease death rates began by county among adults aged 35–64 years and characterized geographic variation.

Methods: We applied Bayesian spatiotemporal models to vital statistics data to estimate the timing (i.e., the year) of increasing county-level heart disease death rates during 1999–2019 among adults aged 35–64 years. To examine geographic variation, we stratified results by US Census region and urban-rural classification.

Results: The onset of increasing heart disease death rates among adults aged 35–64 years spanned the two-decade study period from 1999 to 2019. Overall, 43.5% (95% CI: 41.3, 45.6) of counties began increasing before 2011, with early increases more prevalent outside of the most urban counties and outside of the Northeast. Roughly one-in-five (18.4% [95% CI: 15.6, 20.7]) counties continued to decline throughout the study period.

Conclusions: This variation suggests that factors associated with these geographic classifications may be critical in establishing the timing of changing trends in heart disease death rates. These results reinforce the importance of spatiotemporal surveillance in the early identification of adverse trends and in informing opportunities for tailored policies and programs.

Keywords

Heart disease; Vital statistics; Geography; Mortality

Introduction

Heart disease is the leading cause of death in the United States [1]. Nationally, death rates declined dramatically from the 1960s through the early 2000s, with marked geographic

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variation in the timing of the onset of these declines [2–4]. Declines began in the 1950s in large metropolitan areas and in states in the Northeast and Pacific coast before extending to the rest of the country throughout the 1960s and early 1970s [4, 5].

However, since 2011, national declines in heart disease death rates have stagnated, with some demographic groups and many counties experiencing increasing death rates [6–10]. Unlike the historic geographic pattern in which the southern US experienced the greatest concentrations of higher heart disease death rates and weaker declines, [9–12] increases since 2011 have been observed in counties across the country, with a higher prevalence of increasing death rates in smaller cities and rural counties [13]. These increases have been especially prevalent among adults aged 35–64 years [10, 12, 14, 15]. Deaths among this age group are especially concerning as they are largely preventable [9, 15]. Consequently, these working age adults represent a key population for public health programs and clinical interventions geared toward the primary and secondary prevention of heart disease [9].

Prior county-level studies of these recent increases in heart disease death rates have used a fixed initial year for the timing of the increases (i.e., the year 2011) based on the year of onset of national stagnation [10, 12, 14]. Geographic variation in *when* these recent county-level increases began has not been studied. However, as previously observed with the historic onset of declines, examining the timing of changing trends can reveal geographic and temporal variation that may be masked by national data. Characterizing the timing of these local changes may then provide key data for cardiovascular disease surveillance by better characterizing those places that first experienced adverse trends. These additional data may then inform policies and programs to better respond to these adverse trends within specific communities. Therefore, to describe this geographic variation, this study estimated the timing of onset of increasing heart disease death rates by US county during 1999–2019 among US adults aged 35–64 years and characterized geographic variation in this timing by US Census region and urban-rural classification.

Methods

Data sources

We obtained unsuppressed annual heart disease death counts for ages 35–64 by county of residence for 1999 through 2019 from the National Vital Statistics System of the National Center for Health Statistics (NCHS). Although vital statistics data are available through 2020, we excluded 2020 from this analyses due to increases in heart disease mortality associated with the SARS-CoV-2 pandemic [16]. Heart disease deaths were defined as those with an underlying cause of death listed as ICD-9 codes 390–398, 402, and 404–429, and ICD-10 codes I00–I09, 111, 113, and 120–151. We used NCHS bridged-race estimates for annual county-level populations [17].

The unit of analysis was the county (or county equivalent). Given changes in county definitions during the study period (e.g., the creation of new counties), a single set of 3136 counties based on the most recent county definitions was used for the entire study period.

Estimating heart disease death rates

We estimated annual county-level heart disease death rates for ages 35–64 for the years 1999 through 2019 using a statistical model that produces precise, reliable rates, even in the presence of small numbers of deaths and populations [18, 19]. Specifically, we used a previously published Bayesian conditional autoregressive model that has been used extensively to generate county-level estimates of cardiovascular disease mortality [10–12, 14, 20, 21]. This model is based on the Besag-York-Mollié conditional autoregressive model for spatially-referenced count data and incorporates correlation across space, time, and age group [21, 22]. We fit this model with a Markov chain Monte Carlo (MCMC) algorithm using user-developed code in the R programming language [23]. For each county, we estimated annual death rates as the medians of the posterior distributions defined by the MCMC iterations. Death rates were age-standardized to the 2010 US population using 10-year age groups.

More specifically, we modeled Y_{ikt}, the number of deaths in county i and age group k during year t from population n_{ikt} using a Poisson distribution of the form $Y_{ikt} \sim Pois(n_{ikt}\,\lambda_{ikt})$, where λ_{ikt} is the death rate. To model λ_{ikt}, we assume $ln(\lambda_{ikt}) \sim N(\beta_{kt} + Z_{ikt},\ \tau_k^2)$, where β_{kt} is a random intercept for each group for each year with a vague N(0,100) prior, Z_{ikt} is a spatiotemporal random effect that incorporates correlation between age groups, and τ_k^2 is a variance parameter with a weakly informative gamma prior [24]. Our models accounted for correlation across time, space, and age group by modeling the spatiotemporal random effect (Z_{ikt}) using the multivariate space-time conditional autoregressive (MST-CAR) model based on the multivariate CAR model of Gelfand and Vounatsou [25]. Spatial correlation of the random effect for each county is defined by queen contiguity. Similarly, temporal correlation uses an approach similar to a standard autoregressive order 1 (AR[1]) model with a beta prior. Finally, correlations between age groups were estimated via an unstructured covariance matrix with an inverse Wishart prior [24]. We ran the MCMC algorithm with four chains for 6000 iterations, diagnosing convergence via trace plots for many model parameters and discarding the first 3000 iterations as burn-in.

Estimating the timing of the onset of increasing heart disease death rates

To estimate the timing of the onset of increasing heart disease death rates, we first divided the 21-year study period into seven consecutive three-year intervals (1999–2001, 2002–2004, 2005–2007, 2008–2010, 2011–2013, 2014–2016, and 2017–2019). By identifying the timing of the onset of increases using these three-year intervals instead of a single year, we balanced the granularity of the timing with the precision of the estimated interval.

For each county, we then defined the time of onset of increasing death rates as the interval with the highest probability of including the minimum rate. Rates in years before and after the minimum rate must, on average, be decreasing and increasing, respectively. Therefore, the interval that includes the minimum rate represents the transition from a period of declining death rates to a period of increasing or plateauing death rates. We calculated the probability that the interval included the minimum rate using the MCMC samples from the posterior distributions of heart disease death rates. For each county, we calculated the proportion of samples within each of the seven consecutive three-year intervals that included the county's minimum rate. We then assigned the interval with the highest posterior probability (i.e., most common interval across the MCMC samples) as the interval during which increases began.

Other methods of estimating the timing of changes in trends (e.g., joinpoint regression) are not able to detect changes in trends based on small numbers of events, limiting the ability to make comparison across geographic units with vastly different populations [26]. Our use of the posterior distributions enabled the detection of changes in trends even for counties with small numbers of events or small populations. Additionally, by using the posterior distributions of the death rates, this method accounted for the precision of the underlying rates and was, therefore, more robust than simply selecting the interval that contained the lowest estimated rate.

To verify that the interval containing the minimum rate reflected a transition from decreasing rates to increasing rates, for each county we also calculated the percent change before (from 1999 to the interval midpoint) and after (from the interval midpoint to 2019) the interval of onset of increasing death rates. We calculated percent change as the difference between the later and earlier rate, divided by the earlier rate. Counties with onset of increases in the first interval ($n = 134$) were excluded from percent change calculations before the interval of onset; those with increases in the last interval ($n = 659$) were excluded from percent change calculations after the interval of onset. We performed this calculation using MCMC samples from the posterior distributions of death rates. By using the entire distribution of the rate estimate (instead of only using the point estimate), percent change calculations accounted for the precision of the underlying rates.

Onset of increasing heart disease death rates relative to the national change in trend

To examine onset of increasing heart disease death rates relative to the national change in trend in 2011 [6–8], we grouped the three-year intervals into three categories. The first category represented counties with increases that began prior to the national change in trend and included all three-year intervals prior to 2011. The second category included counties with increases that began after 2011 but before the final interval. The third category included counties that did not experience increasing death rates (i.e., those counties with lowest rates in the final interval). We then used the posterior distributions of the assigned categories to calculate the percent of counties and 95% credible intervals (95% CI) within each of these categories. By using this distribution, our percentages account for uncertainty in the underlying assignment of the category.

Geographic variation

To examine geographic variation in the onset of increasing death rates, we first mapped the interval of onset. We also stratified our results on two variables that further describe the geographic patterns: region and urban-rural classification. We defined regions as the four US Census regions (Northeast, Midwest, South, West). For urban-rural classification, we used the 2006 National Center for Health Statistics urban-rural classification scheme for counties

[27]. We selected this version of the classification (rather than the 2013 version) because it better represented the classification at the beginning of the study period.

Inclusion criteria

For a county to be included in this analysis, we required that the estimated heart disease death rates were reliable (i.e., the credible interval width was less than the point estimate) and the population was greater than 100 for each year (1999–2019). These requirements ensured that we only reported reliable heart disease death rates in sufficiently large populations and that the same set of counties (n = 3116) was used for all years of the study period.

Results

Distributions of the onset of increasing heart disease death rates

Among 3116 included counties, the onset of increasing heart disease death rates among adults aged 35–64 years spanned the two-decade study period from 1999 through 2019 (Table 1). Overall, 43.5% (95% CI: 41.3, 45.6) of counties began increasing prior to the national change in trend in 2011. Geographically, earlier increases were concentrated in a band of counties from Oklahoma through Iowa and Tennessee (Fig. 1). Later increases were more widely distributed across the country.

One hundred thirty-four counties (4.3% of counties) had lowest rates in the first interval (Table 1). For these counties, trends in heart disease death rates from the first interval through 2019 increased or occasionally plateaued (median 14.2%, [10th, 90th percentiles: −1.1%, 38.3%]). Conversely, 659 counties (21.1% of counties) had lowest heart disease death rates in the last interval. For these counties, the median percent change from 1999 through the last interval was consistently negative (median: −26.3% (10th, 90th percentiles: −39.9%, −10.7%)), indicating that, on average, heart disease death rates in these counties continued to decline and did not increase during the study period.

Onset of increasing heart disease death rates by census region

Increasing heart disease death rates began earlier in counties outside of the Northeast region (Table 2, Fig. 2). Among counties outside of the Northeast, 45.7% (95% CI: 40.8, 48.9), 46.8% (95% CI: 44.1, 49.5), and 35.6% (95% CI: 30.5, 40.0) of counties in the Midwest, South, and West, respectively, began to increase prior to the national change in trend in 2011. Conversely, only 27.2% (95% CI: 21.2, 33.6) of counties in the Northeast were increasing prior to the national change in trend. Compared to the Northeast, the percent of counties with increases prior to the national increase was 1.7 (95% CI: 1.4, 2.1), 1.7 (95% CI: 1.4, 2.2) and 1.3 (95% CI: 1.0, 1.7) times greater in the Midwest, South, and West, respectively (Table 2). Some counties within each region did not experience increases during the entire study period, ranging from 16.1% (95% CI: 13.8, 18.6) of counties in the South to 24.2% (95% CI: 20.2, 29.3) of counties in the West (Table 2, Fig. 3).

Onset of increasing heart disease death rates by urban-rural classification

Increasing heart disease death rates began earlier outside of the large central metro counties (Table 2, Fig. 2). Among these counties, 27.7% (95% CI: 23.4, 32.5), 38.9% (95% CI: 34.3, 42.8), 44.1% (95% CI: 39.7, 49.1), 46.2% (95% CI: 42.7, 49.8), and 48.4% (95% CI: 45.4, 51.9) of large fringe metro, medium metro, small metro, micropolitan, and noncore counties, respectively, began to experience increasing heart disease mortality prior to 2011. Conversely, approximately one-fifth (17.5% [95% CIL 9.5, 23.8]) of large central metro counties began to increase before the national change in trend in 2011 (Fig. 2).

Roughly two-in-five (38.1% [95% CI: 27.0, 46.0]) of large central metro counties declined throughout the study period (Table 2). Compared to these large central metro counties, large fringe metro, medium metro, small metro, micropolitan, and noncore counties were roughly 50% less likely to decline for the entire study period (ratios of 0.6 [95% CI: 0.5, 0.8], 0.5 [95% CI: 0.4, 0.7], 0.4 [95% CI: 0.3, 0.6], 0.5 [95% CI: 0.4, 0.6], and 0.5 [95% CI: 0.3, 0.6], respectively) (Table 2, Fig. 3).

Discussion

In this study of the timing of changing county-level trends in heart disease mortality, we found that national data have masked both temporal and geographic variation in the onset of recent increases in heart disease death rates among adults aged 35–64 years. The timing of local increases spanned over two decades, with the earliest increases in the early 2000s concentrated outside of the Northeast and outside of central metro counties. However, some counties in all regions and all urban-rural categories continued to experience declining heart disease death rates during the entire study period.

During the latter half of the 20th century, heart disease mortality experienced strong national declines [2–4]. These national improvements have been equally attributed to advances in prevention and treatment [28]. However, at a more geographically granular level, these historic declines varied markedly in magnitude and began at different times, with the timing differing by urban-rural classification, region, and their corresponding socioeconomic characteristics [2, 3, 13].

Our findings regarding the recent onset of increasing heart disease death rates mirror this variation in the timing of historic declines [2, 3]. The Northeast region fared best in the timing of both declining and increasing death rates, with most communities in the region experiencing the early onset of declining heart disease death rates and the late onset of increasing heart disease death rates. Likewise, the onsets of both declines and increases exhibited a strong urban-rural gradient, with the most urban areas experiencing the earliest onset of declines and the latest onset of increases. Although the study populations and geographic units in the earlier studies documenting onset of declines differed slightly from our study (ages 35–74 vs. 35–64, state economic areas vs. counties, white population vs. all racial and/or ethnic groups, respectively), this symmetry in findings between the timing of historic declines and recent increases reinforces the importance of place-based factors (rather than prevention and treatment alone) in establishing when trends in heart disease death rates change.

Our observed differences by urban-rural classification suggest additional insight into the drivers of the timing of changing trends in heart disease death rates. Since the mid-1990s, rural counties have traditionally experienced excess in all-cause mortality stemming from physician shortages and lower health insurance coverage, which are in turn rooted in socioeconomic factors [29–31]. These same socioeconomic and health systems factors contribute to geographic disparities in cardiovascular disease mortality, especially in the Southern US where heart disease death rates are highest and historic declines in those rates have been slowest [10, 13, 32]. Likewise, limited access to medical settings may compound poor health among working age adults, who are less engaged with the medical system and who are less aware of key cardiovascular disease risk factors (e.g., hypertension) [33–35]. Consequently, the earlier onset of increasing heart disease mortality in counties outside of highly urban centers may reflect a geographic inequity in access to both the medical system and to environments that facilitate the prevention and treatment of heart disease.

However, even within these urban-rural and regional classifications, the timing of recent increases varied such that some counties within each category continued to experience declining heart disease death rates throughout the study period. Future work may continue to explore these associations and to examine the complex interplay between local-level socioeconomic conditions, timing of changes in primary and secondary prevention, and the timing of changing trends, especially within the context of racial and/or ethnic disparities in heart disease mortality. Importantly, these studies may benefit from examining positive characteristics of the roughly 20% of resilient counties that defied national trends and continued to decline.

These results may also directly inform the public health surveillance of cardiovascular disease, which is especially important since deaths among these working age adults are preventable [9]. The geographic and temporal variation observed within our results reinforce the critical nature of collecting, analyzing, and monitoring local chronic disease outcomes [36]. Our results demonstrate that county-level changes in trends may serve as bellwethers for national changes, allowing quicker, more geographically specific implementation of actions to reverse adverse trends long before the trends become apparent at the national level. By the time national trends in heart disease death rates changed in 2011, more than one-in-five (26.3 million) adults aged 35–64 years lived in counties with increasing death rates (Supplemental Table 1, Supplemental Fig. 1). These individuals comprise communities that represent key opportunities for the prevention of cardiovascular health risk factors, treatment of heart disease, and improvement of heart health. Prevention and treatment opportunities may benefit from occurring outside of the typical medical settings, including in communities and at workplaces, given the potential for limited medical access among these working age adults and in communities outside of urban population centers [29–31].

Limitations

This analysis is subject to at least four limitations. First, cause of death listed on death certificates may be misclassified [37, 38]. However, our use of the broad category of “all diseases of the heart” reduces this potential misclassification [39, 40]. Additionally, this outcome represents the most comprehensive measure of heart disease burden that is available at the county-level. Second, small numbers of deaths and small populations may lead to imprecise rates and uncertainty in the assigned interval of onset. Our Bayesian model allowed us to generate more precise rates than would have been possible using non–suppressed NCHS mortality data. However, some rates remained imprecise and these were suppressed. Using this set of precise rate estimates, we then estimated the interval of onset by using MCMC samples from the posterior distributions of heart disease death rates. The resulting posterior probabilities of the estimated intervals were much higher than the probability of selecting an interval by chance, indicating more precision and greater certainty in the estimate (Supplemental Fig. 2). The definition of these intervals represents a third limitation. We chose three-year intervals to balance precision of the estimates and temporal granularity. In a sensitivity analysis, we performed the analysis using 2-year intervals. The observed patterns did not noticeably change using this definition, but the posterior probabilities using this definition were much smaller (Supplemental Table 2, Supplemental Fig. 3). Finally, the potential heterogeneity of health outcomes within counties may mask more geographically granular disparities [29]. However, the county is the smallest geographic level for which national death data are available.

Conclusion

Over the span of two decades, counties across the country began to experience increasing heart disease death rates among working age adults, foreshadowing the national change in trend by a decade. Variation in this timing by region and urban-rural classification suggests that factors associated with these geographic classifications may be critical in establishing the timing of changing trends in heart disease death rates. These results further reinforce the key role of spatiotemporal surveillance in the early identification of adverse trends and in informing subsequent opportunities for tailored policies and programs.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

The findings and conclusions in this report are those of the authors and do not necessarily represent the official position of the Centers for Disease Control and Prevention.

Abbreviations:

MCMC	Markov chain Monte Carlo
95% CI	95% credible interval
NCHS	National Center for Health Statistics

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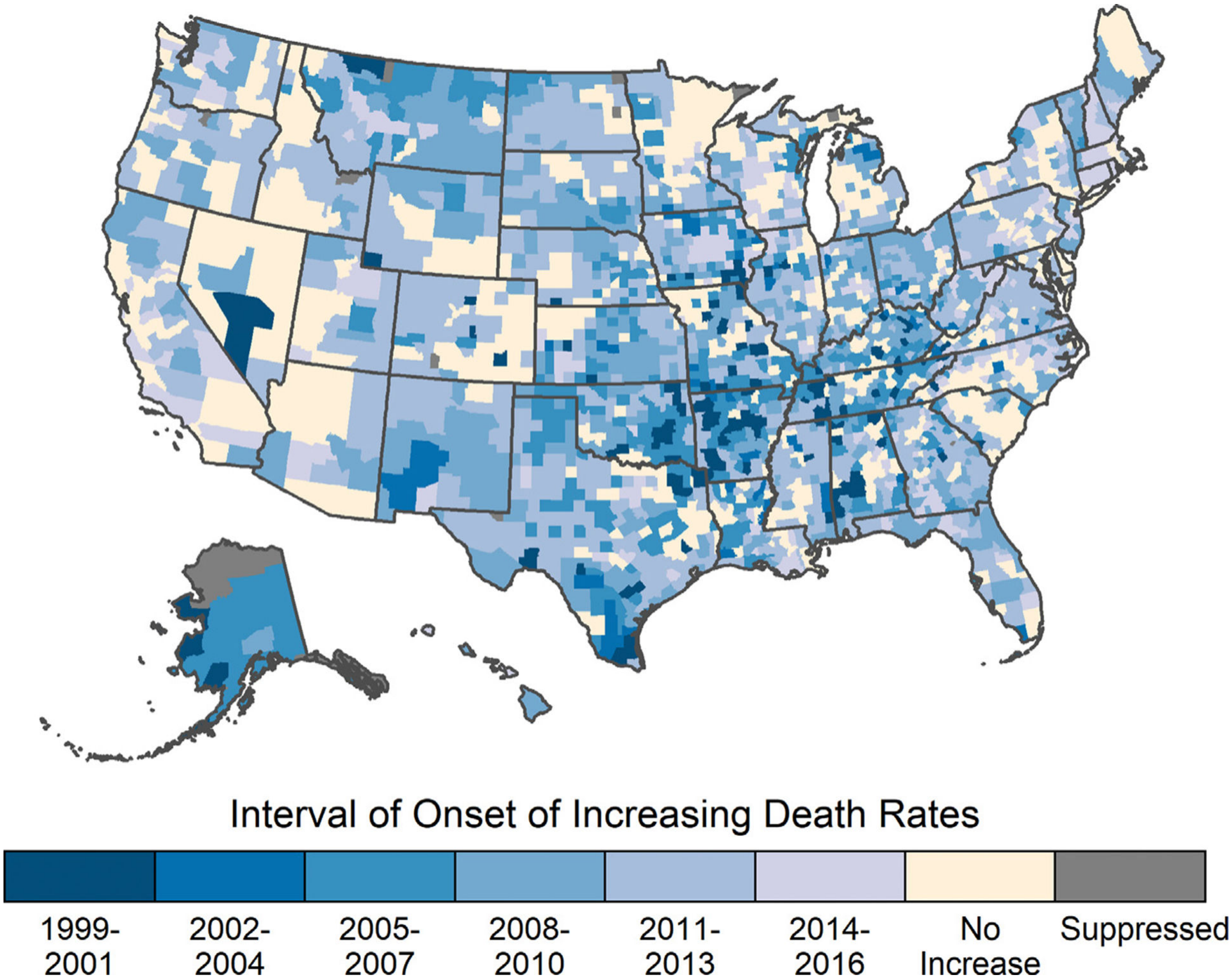

Fig. 1.
Interval of onset of increasing heart disease death rates in adults ages 35–64, by county, United States, 1999–2019.

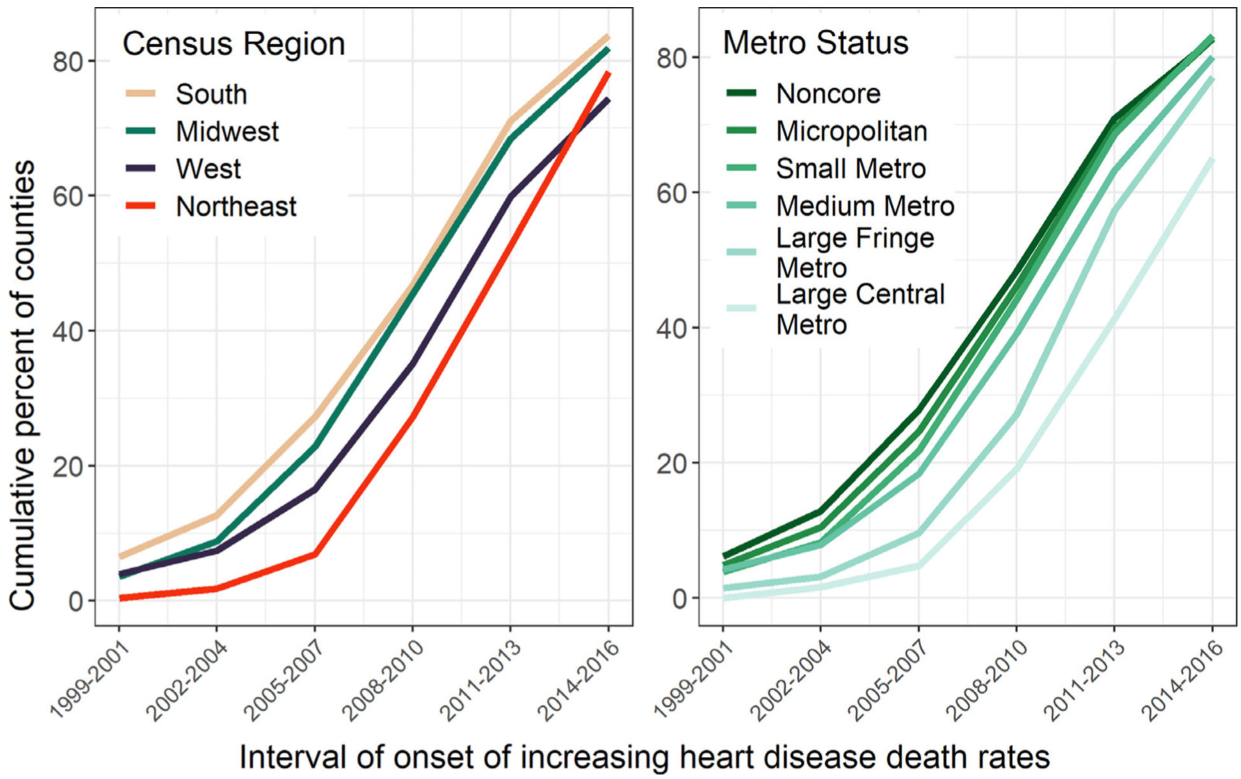

Fig. 2.

Cumulative percent of counties experiencing increasing heart disease death rates by US census region and urban-rural classification, 1999–2019. Note: Counties included in the earliest interval (1999–2001) may have started to increase prior to 1999.

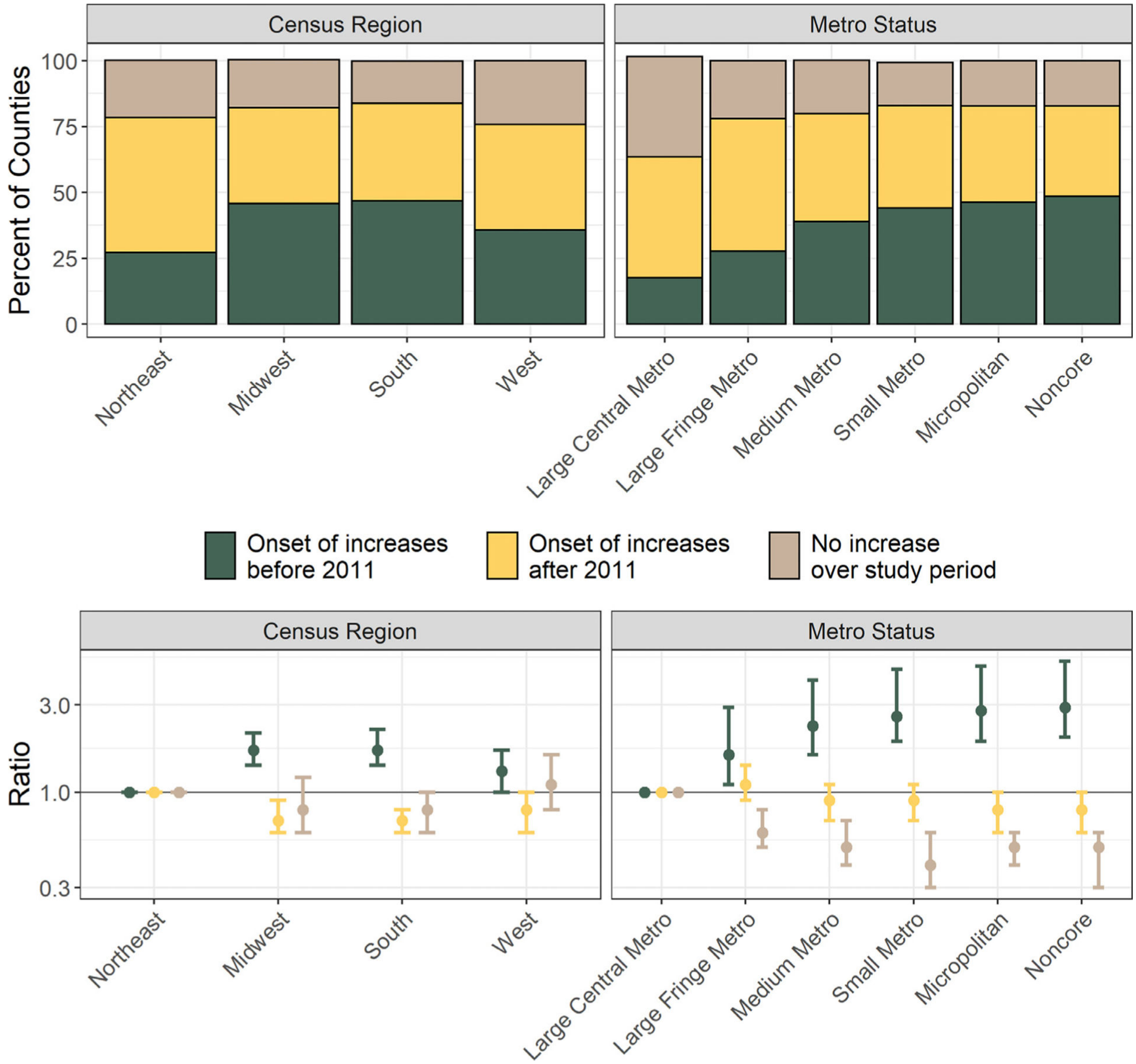

Fig. 3.

Percent of counties with onset of increasing heart disease death rates before and after the national onset in 2011, by US census region and urban-rural classification.

Table 1

Distributions of county-level heart disease death rates and trends by interval of onset of increasing heart disease death rates

Interval of onset of increasing heart disease death rates*	Number of counties with onset of increases during this interval (%)	Median death rate at interval midpoint (10th, 90th percentiles)	Median total percent change before interval midpoint (10th, 90th percentiles)	Median total percent change after interval midpoint (10th, 90th percentiles)
1999–2001	134 (4.3)	145.3 (89.0, 208.2)	N/A	14.2 (−1.1, 38.3)
2002–2004	70 (2.2)	127.0 (77.4, 181.5)	−5.1 (−13.6, 0.5)	12.7 (−2.0, 30.0)
2005–2007	373 (12.0)	118.6 (72.3, 177.8)	−13.2 (−24.6, −3.5)	16.7 (3.0, 32.7)
2008–2010	668 (21.4)	102.8 (70.8, 160.1)	−21.7 (−32.2, −9.6)	12.3 (2.7, 26.6)
2011–2013	926 (29.7)	90.9 (58.6, 150.8)	−25.8 (−37.8, −12.9)	8.6 (1.1, 19.6)
2014–2016	286 (9.2)	81.2 (53.1, 129.9)	−30.1 (−41.0, −17.0)	5.4 (−0.7, 13.6)
No increase†	659 (21.1)	94.5 (60.2, 165.8)	−26.3 (−39.9, −10.7)	N/A

*Interval of onset of increasing heart disease death rates defined as the interval with the highest probability of including the lowest death rate during 1999–2019.

†Counties in this category had lowest heart disease death rates in the last interval (2017–2019).

Table 2

Percent of counties experiencing increasing heart disease death rates relative to the national changes in trend in 2011, by US census region and urban-rural classification

	Percent of counties (95% CI)			Ratio of percentages (95% CI)		
	Onset of increases prior to 2011	**Onset of increases in 2011 or later**	**No increases**	**Onset of increases prior to 2011**	**Onset of increases in 2011 or later**	**No increases**
Overall	43.5 (41.3, 45.6)	38.1 (36.1, 40.9)	18.4 (15.6, 20.7)	–	–	–
Region Northeast ($n = 217$)	27.2 (21.2, 33.6)	51.2 (43.8, 58.1)	21.7 (15.7, 28.1)	Ref	Ref	Ref
Midwest ($n = 1051$)	45.7 (40.8, 48.9)	36.3 (32.5, 40.2)	18.3 (14, 22.1)	1.7 (1.4, 2.1)	0.7 (0.6, 0.9)	0.8 (0.6, 1.2)
South ($n = 1418$)	46.8 (44.1, 49.5)	37.0 (33.7, 40.4)	16.1 (13.8, 18.6)	1.7 (1.4, 2.2)	0.7 (0.6, 0.8)	0.8 (0.6, 1.0)
West ($n = 430$)	35.6 (30.5, 40.0)	40.2 (34.2, 45.8)	24.2 (20.2, 29.3)	1.3 (1.0, 1.7)	0.8 (0.6, 1.0)	1.1 (0.8, 1.6)
Urban-rural classification Large central metro ($n = 63$)	17.5 (9.5, 23.8)	46.0 (36.5, 55.6)	38.1 (27.0, 46.0)	Ref	Ref	Ref
Large fringe metro ($n = 354$)	27.7 (23.4, 32.5)	50.3 (44.4, 55.6)	22.0 (18.1, 26.3)	1.6 (1.1, 2.9)	1.1 (0.9, 1.4)	0.6 (0.5, 0.8)
Medium metro ($n = 332$)	38.9 (34.3, 42.8)	41.0 (36.4, 45.8)	20.2 (16.9, 23.8)	2.3 (1.6, 4.1)	0.9 (0.7, 1.1)	0.5 (0.4, 0.7)
Small metro ($n = 340$)	44.1 (39.7, 49.1)	38.8 (33.5, 43.8)	16.5 (12.6, 20.6)	2.6 (1.9, 4.7)	0.9 (0.7, 1.1)	0.4 (0.3, 0.6)
Micropolitan ($n = 691$)	46.2 (42.7, 49.8)	36.6 (32.6, 40.5)	17.2 (13.9, 20.3)	2.8 (1.9, 4.9)	0.8 (0.6, 1)	0.5 (0.4, 0.6)
Noncore ($n = 1336$)	48.4 (45.4, 51.9)	34.4 (31.6, 38.2)	17.2 (13.4, 20.0)	2.9 (2, 5.2)	0.8 (0.6, 1)	0.5 (0.3, 0.6)