THE EFFECT OF APPALACHIA AND STATE BORDERS ON PATTERNS OF MORTALITY IN THE FIVE CENTRAL APPALACHIAN STATES

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1. INTRODUCTION

Appalachia manifests some of the highest death rates in the nation (Halverson *et al.*, 2004), with many of the worst counties clustered in the central Appalachian areas of Kentucky, North Carolina, Tennessee, West Virginia, and Virginia. Previous research on mortality in Kentucky reveals relatively high mortality rates throughout the state. For instance, Kentucky has the fifth highest death rate in the nation at 999.8 deaths per 100,000. Kentucky's age-adjusted mortality rate for men is 1,238.2 (4th) and for women is 830.1 (5th). This research also highlights significant differences between Appalachian and non-Appalachian counties (Hare, 2004). Striking inequalities in wealth, employment, and education divides Kentucky's population and are complexly associated with health outcomes and disparities. Similarly, previous research on the entire Appalachian region reveals a general pattern of relatively high mortality rates throughout (Halverson *et al.*, 2004). While several previous studies compare Appalachian and non-Appalachian health inequalities and general variability in mortality across Appalachia, they have not adequately addressed variability across Appalachian states.

The study of mortality rates and their variability has a long history. In addition, advances in GIS and spatial analysis, along with the compilation of massive spatially-referenced health data sets are generating new ways to examine health-related issues. Projects such as the *Atlas of United States Mortality* (Pickle *et al.*, 1996) have motivated numerous researchers to explore the significance of and differences between various measures of mortality (Goldman and Brender, 2000), the appropriateness of particular visual methods for representing mortality data in geographic contexts (James *et al.*, 2004), and the application of spatial statistical methods to mortality data (James *et al.*, 2004; Rushton, 2003).

In this paper, I use spatial statistical techniques to assess the variation in mortality across the five central Appalachian states and explore the nature of regional and state boundaries. Specifically, this study addresses two research questions:

1) How are mortality rates distributed across the central Appalachian states?
2) What effects do regional and state borders have on variability in mortality rates?

Results show that while Appalachia is generally associated with relatively high mortality rates, the pattern is highly variable. Appalachia's politically-defined boundaries only weakly correlate with high mortality rates, and clusters of high rates are scattered both within and outside Appalachia. In addition, a pattern of association with state borders is evident in the distribution of mortality rates. These relationships suggest that differences in state-level policies are important influences on the spatial pattern of mortality in this region.

2. BACKGROUND

GIS (Hochberg *et al.*, 2000) and developments in spatial analysis (Haining, 2003) have revolutionized the geographic exploration of social, economic, and environmental issues, including the geography of health (Gatrell, 2002; Meade and Earickson, 2000). These tools encourage research directed at the "quantitative analysis of health-related phenomena in a spatial setting" (Gatrell and Senior, 1999, pg. 925) through disease mapping, geographical correlation studies, risk assessment, and disease clustering (Cromley, 2003; Elliot *et al.*, 2000). Recently developed techniques further enhance the study of health geography through geographically weighted regression (Fotheringham *et al.*, 2002), boundary analysis (Jacquez *et al.*, 2000), and space-time analysis (Jacquez *et al.*, 2005; Rey and Janikas, 2004).

The five-state area encompassing central Appalachia encompasses 195,508 square miles and encompasses three zones: the eastern coastal area, the Appalachian area that crosses northeast-southwest through the center of the region, and the plains and hills to the west (Figure 1). The region's population in 2000 was 26,667,224, of which 28.6 percent lived in Appalachian counties (Table 1). The region's total population density was 136.4 persons per square mile and within Appalachia only 90.4 (U.S. Census Bureau, 2000). The population was 76.6 percent non-Hispanic white, 16.2 percent black, and 3.3 percent Hispanic. The remaining was primarily divided among Asians and Native Americans. The median age was 37.6 years, 29.5 percent of the population was age 21 or below, and 11.9 percent were age 65 or older.

TABLE 1
SUMMARY STATISTICS FOR THE STATES USED IN THIS STUDY

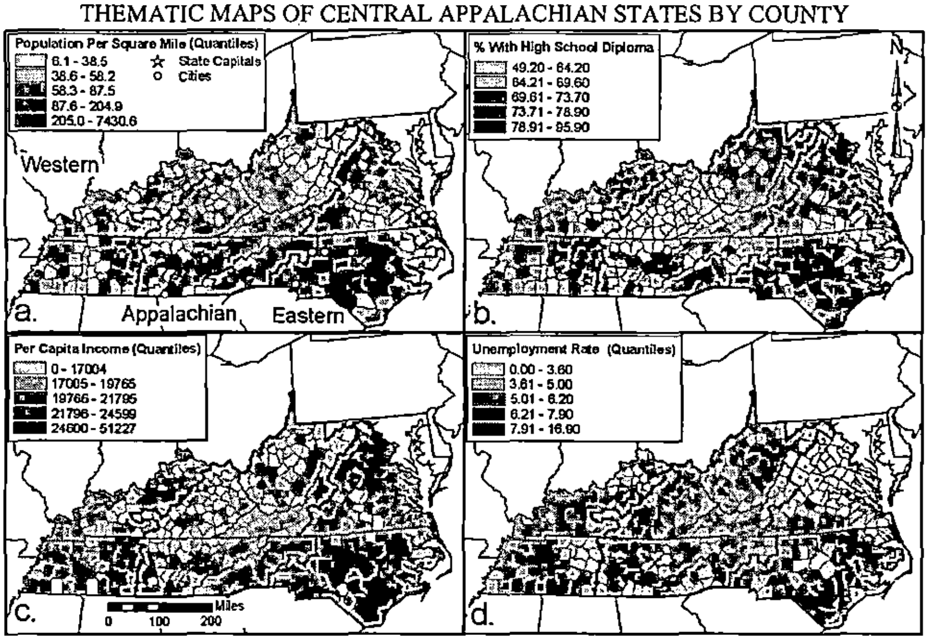
State/Region	Total Area Square Miles	Area in Appalachia	Total Population	Population in Appalachia
Kentucky	40,320	17,907	4,041,769	1,141,511
North Carolina	49,048	12,016	8,049,313	1,526,207
Tennessee	42,092	19,736	5,689,283	2,479,317
Virginia	39,820	10,369	7,078,515	665,177
West Virginia	24,229	24,229	1,808,344	1,808,344
Total	195,508	84,257	26,667,224	7,620,556
West Zone	44,769	0	6,110,224	0
Appalachian Zone	84,257	84,257	7,620,556	7,620,556
Eastern Zone	66,482	0	12,396,444	0

Source: (U.S. Census Bureau, 2000).

Approximately 7.6 million people live in central Appalachia (Figure 1a) (Pollard, 2003). Central Appalachia is associated with several indicators of poverty such as *per capita* income (Figure 1c) and of the region's population, 15.8 percent live in poverty versus only 11.0 percent of non-Appalachian central Appalachians. Differences between Appalachian and non-Appalachian areas are also evident in unemployment (Figure 1d), and educational attainment (Figure 1b). It is clear that states containing portions of Appalachia face unique economic and social challenges (Couto, 1994; Pollard, 2003).

Until recently, relatively little investigation of health variation in this region has been conducted, despite the striking economic and social disparities evident. The thematic map of age-adjusted mortality rates by county for 1996 through 2002 reveals clear spatial patterning of variability (Figure 2a). General studies of health factors in Appalachia reveal differences in health status and mortality based on poverty levels (McDavid *et al.*, 2003), race (Barnett *et al.*, 2000), urban vs. rural areas (Hare, 2004), and sex (Hare, 2004). Fewer studies have been conducted on spatial variation in health factors in the region.

FIGURE 1
THEMATIC MAPS OF CENTRAL APPALACHIAN STATES BY COUNTY



Source: Area Resource File health resource information system (US DHHS, 2003).

The most recent assessment of Appalachian morbidity and mortality paints a grim picture (Halverson *et al.*, 2004). In addition to high mortality rates, the central Appalachian states have high proportions of smokers (30.7 percent), prevalence of obesity (33.3 percent), and child poverty (25.5 percent). Research focusing on Appalachia also reveals poorer health status than other areas of the U.S. For instance, Lengerich *et al.* (2003) found that incidence of lung, colon, rectum, and cervical cancer are significantly higher in Appalachian Kentucky, Pennsylvania, and West Virginia than in other regions. Stensland *et al.* (2002) identified several challenges to the improvement of health service availability in Appalachia, including a lack of hospital-affiliated substance abuse treatment services in distressed counties, a lack of hospital-affiliated psychiatric services, and a lack of obstetric care.

3. METHODS

All data in this study are county-level and cover the 505 counties of the five-state area. The mortality data are from the Compressed Mortality File (US DHHS 2004) and are available only at the county-level. I examine total mortality as a broad reflection of public health status and heart-related mortality due to the previously identified association between Appalachia and elevated heart-related mortality rates (Halverson *et al.*, 2004). I calculated age-adjusted mortality rates using the direct method and the year 2000 U.S. standard population distribution (Anderson and Rosenberg, 1998) to reduce the effect of age-based mortality variability and enhance the comparison of populations with different age structures (Goldman and Brender, 2000; Kulldorf, 1999; Rushton, 2003). The use of areal aggregated data raises the issues of scale-dependent patterns and rate heterogeneity (Messner and Anselin, 2002). To alleviate these problems, I use mortality data at the finest scale available, calculate rates using counts from multiple years to provide larger frequencies, and smooth the rates using a local empirical Bayes estimator (Haining, 2003).

The socioeconomic variables used for comparison with mortality rates are from the Area Resource File health resource information system (US DHHS, 2003). I selected several variables that previous studies show to be reliably associated with mortality generally (Gatrell, 2002, pg. 121-132) and in the Appalachian region specifically (Hare, 2004).

I use ESRI's ArcGIS 9 for data processing and visualization and GeoDa 0.9.5-i for a variety of exploratory spatial data analysis techniques. GeoDa is a free collection of software tools for a variety of spatial analysis techniques (Anselin, 2003 & 2004) and supports dynamic and interactive analysis of linked tables, charts, and maps. The spatial distributions of mortality rates and socioeconomic variables were assessed using a variety of thematic maps, charts, and spatial statistics, including univariate Moran's I, Moran Scatterplots, and univariate Local Moran LISA cluster maps (Anselin, 2003 & 2004). I used GeoDa's functions for bivariate Moran's I, bivariate Local Moran LISA cluster maps, and spatial regression to assess relationships between the mortality rates and the selected socioeconomic potential covariates.

4. SPATIAL VARIATION IN CENTRAL APPALACHIAN MORTALITY RATES

Preliminary data analysis revealed complex patterns (Figure 2) and significant spatial autocorrelation (Table 2). Thematic maps show mortality for all population categories manifesting a consistent pattern (Figure 2). A long narrow zone of low rates runs southwest from the northern border of Virginia to the southwest corner of North Carolina and separates two broad zones of high mortality rates. This zone encompasses both sides of the eastern border of Appalachia and appears to follow the West Virginia, Kentucky, and Tennessee borders. The largest zone of high mortality rates encompasses all of West Virginia, Kentucky, and the Tennessee. Eastern Kentucky, centered within this zone, contains a tight cluster of the highest mortality rates. A smaller and more heterogeneous region of high mortality rates is present in the eastern half of North Carolina and the southeastern corner of Virginia.

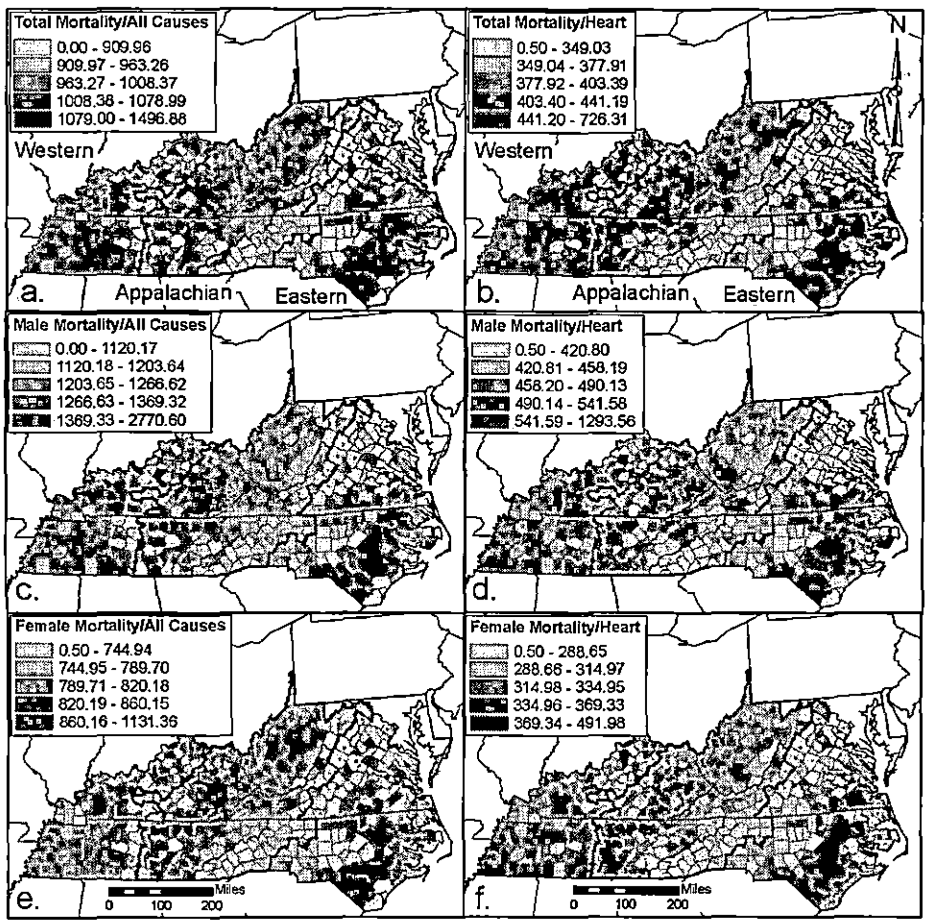
TABLE 2
RESULTS OF TESTS FOR SPATIAL DEPENDENCE

Category	Variables	Univariate Moran's I	Bivariate Moran's I with Total Mortality
All Causes	Total Mortality	0.3301 ***	Na
	Male	0.2466 ***	Na
	Female	0.2698 ***	Na
Heart-Related	Total Mortality	0.3735 ***	Na
	Male	0.2782 ***	Na
	Female	0.3436 ***	Na
Socioeconomic Variables	Population Per Mile2	0.4175 ***	-0.1669 ***
	% High School Graduates	0.1673 **	-0.1918 ***
	Per Capita Income	0.1256 ***	-0.1858 ***
	Unemployment Rate	0.4644 ***	0.2508 ***

*** P ≤.001 ** ≤.01 * ≤.05

All variables tested are positively spatially associated. Heart-related Mortality for all categories have slightly higher Moran's I's than total mortality. These results indicate that the data contradict the statistical assumption of the independence of observations and underlying spatial effects are present that can distort the results of statistical analyses (Messner and Anselin, 2002). To alleviate these problems, I selected spatial regression techniques that control for spatial effects, such as spatial dependence and heterogeneity and reduce the subjectivity in the interpretation of complex patterns by providing inferential tests of spatial patterns. The interpretive implication of these results is that mortality rates are distributed in statistically significant clusters. Furthermore, the bivariate Local Moran tests are significant for all comparisons of mortality rates with selected socioeconomic variables (Table 2). These results indicate a clustering of high mortality rates in areas with low population densities, low rates of high school graduation, low per capita incomes, and high unemployment rates.

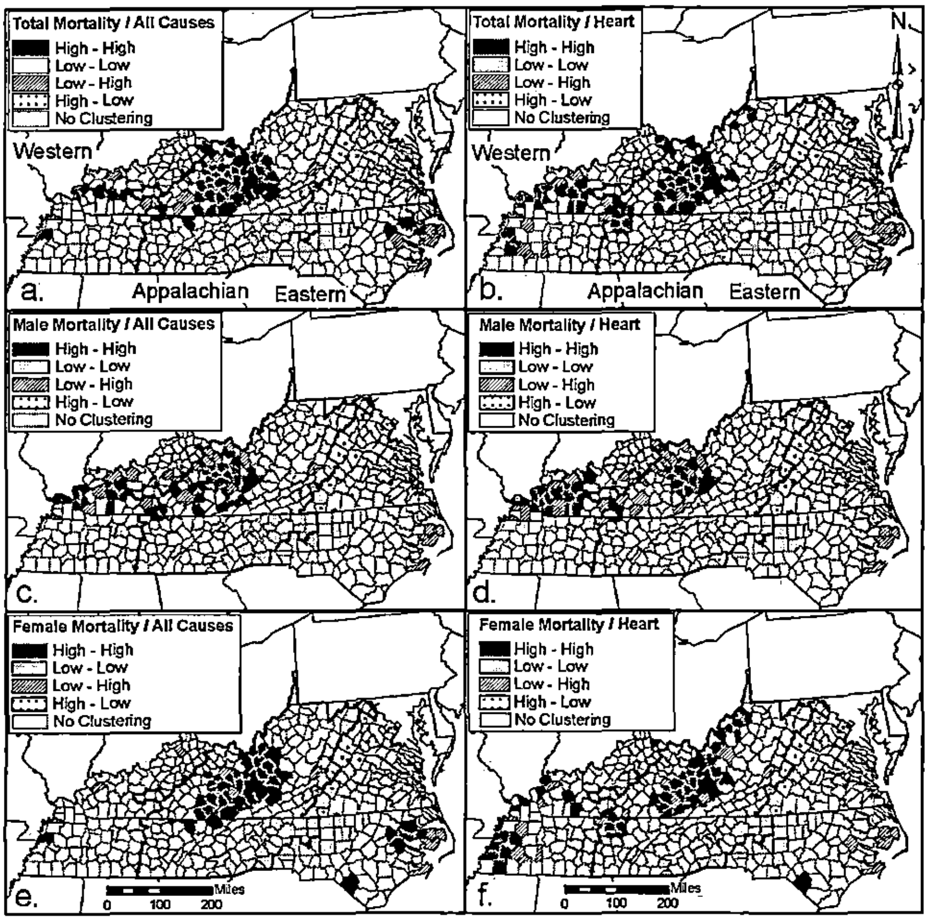
FIGURE 2
THEMATIC MAPS OF MORTALITY RATES BY CAUSE AND SEX



Source: Compressed Mortality File (U.S. Dept. of Health and Human Services, 2004).

The LISA cluster maps highlight the same zones of high and low mortality rates and reinforce the subjective assessment of these patterns (Figure 3). Local Indicators of Spatial Autocorrelation (LISA) compare values in specific locations with those of their neighbors and test the null hypothesis of spatial randomness in their associated distributions. LISA techniques applied to a single variable highlight statistically significant clusters of positive or negative spatial autocorrelation. The LISA cluster maps identify the long narrow band of low mortality rates as a statistically significant area containing counties with low mortality rates surrounded by other counties with low mortality rates.

FIGURE 3
UNIVARIATE LISA CLUSTER MAPS OF MORTALITY RATES



Source: Compressed Mortality File (U.S. Dept. of Health and Human Services, 2004).

The LISA cluster maps also show sets of counties with high mortality rates surrounded by areas of high mortality rates (Figure 3), such as in southeast North Carolina. The LISA cluster maps, however, do not identify most counties in this area as members of statistically significant clusters. All of the LISA cluster maps show some counties with low mortality rates surrounded by counties with high rates. Only total mortality for all causes and female mortality for all causes have more than one county identified as having high rates surrounded by others with high rates. Similarly, the western areas of high mortality rates have more variation by categories as well as differences between categories. Eastern Kentucky has the largest and most homogeneous set of counties with high mortality rates surrounded by others with high rates. It is the only area identified for female mortality for all causes. The LISA cluster maps of the other categories all show broader areas of high mortality rates and additional small clusters. For instance, total and male mortality for all causes show scatters of high mortality areas through the rural southern region in Kentucky west of Appalachia. All maps of heart-related mortality show additional coherent clusters of high mortality west and southwest of eastern Kentucky. Male mortality for heart-related conditions shows a large cluster of high mortality filling the western tip of Kentucky. Female mortality for heart-related conditions shows two small clusters of high mortality. One cluster is located just south of the Kentucky boarder in the north-central area of Tennessee. The other cluster is located along the western edge of Tennessee.

These LISA cluster maps also show two different patterns in relation to Appalachian and state borders. The band of low mortality rates starts in the northeast corner of Virginia and ends at Virginia's border with West Virginia and Appalachia. Further south, the band straddles the Appalachian border and continues to the state border with Tennessee. The maps do not identify other clusters coinciding with Appalachia's borders. Kentucky's borders with West Virginia, Virginia, and Tennessee closely demarcate the largest cluster of high mortality rates. Furthermore, different categories produce different patterns in Kentucky and Tennessee. Zones of high male mortality are confined to Kentucky. Zones of high female mortality for heart-related conditions, however, are located in both Kentucky and Tennessee.

I used a spatial regimes regression approach to explore the differential effects of regions on county-level mortality rates. Dummy variables coded for the categorical classifications of each county in the analysis including for each state and for Appalachian vs. non-Appalachian areas. The inclusion of *per capita* income controls for poverty, which previous research identifies as a primary determinant of mortality. The conventional, non-spatial model of mortality produced an adjusted R-squared of 0.300919 and an Akaike information criterion of 6024.03. As expected, *per capita* income is negative and significant (Table 3). The counties of Kentucky, North Carolina, Tennessee, and West Virginia are positively associated with high mortality rates, but Kentucky has the largest coefficient by almost double. The coefficient for North Carolina is the smallest and reflects the complex mix of low to moderate rates of mortality across the state. The statistically significant effect of Appalachia contradicts the expectations of higher mortality rates, but it is consistent with the results of thematic and LISA cluster maps.

TABLE 3
RESULTS OF REGRESSION OF COUNTY-LEVEL MORTALITY RATES

Model	Independent Variables	Coefficient	Std. Error	T-Statistic/ Z-Value	
OLS	Constant	1083.313	15.2494	71.03974	***
	Per Capita Income	-0.006666726	0.0006283241	-10.61033	***
	Kentucky	122.2067	12.42561	9.835066	***
	North Carolina	32.08614	13.14845	2.440298	*
	Tennessee	67.29322	13.48625	4.989766	***
	West Virginia	58.98812	17.40668	3.388821	***
	Appalachia	-8.305638	10.05995	-.8256144	
Spatial Error	Constant	1083.791	16.57821	65.34777	***
	Per Capita Income	-0.006258906	0.0005826629	-10.7419	***
	Kentucky	116.0018	18.60704	6.234295	***
	North Carolina	20.58697	18.66031	1.103249	
	Tennessee	62.23623	19.69186	3.160506	**
	West Virginia	45.10325	24.32737	1.854013	
	Appalachia	-9.191012	13.72953	-0.6694336	
	Lambda	0.4333894	0.05363308	8.080185	***

*** P ≤.001   ** ≤.01   * ≤.05

I used a set of spatial econometric diagnostic tests for heteroskedasticity, spatial lag, and spatial error dependence to assess the extent of spatial effects. All tests for heteroskedasticity, spatial lag, and spatial dependence were significant in the residuals of the OLS model, except for the robust test of spatial lag. The analysis reveals that Kentucky, and to a lesser extent Tennessee and West Virginia, have comparatively high mortality rates, even when controlling for variation in *per capita* income. Furthermore, the estimates indicate a larger residual variance for the model in the areas identified by thematic and LISA cluster maps as clusters of high rates, which suggests a poorer fit in these areas.

Given the evidence from regression coefficients, diagnostic tests, and spatial pattern of the residuals, for spatial variation and distinct spatial regimes in the region, I implemented a spatial regression model using GeoDa. GeoDa provides functions for modeling either spatial lag or spatial error models. Spatial lag models imply that geographic clustering results from the effects each zone has on adjacent zones and is consistent with processes of diffusion. Spatial error models suggest that clustering results from the effects of unmeasured variables. The evidence indicates the need for a spatial error model for mortality in the region.

The spatial error model of mortality produced a pseudo R-squared of 0.41 and an Akaike information criterion of 5967.44. While the pseudo-R-squared is not directly comparable to the R-squared of the OLS model, the two values indicate a significant improvement over the previous model. The spatial autoregressive coefficient is 0.44 and is highly significant ($p <$ 0.0000000). Again, *per capita* income is negative and significant (Table 3). Of the states, only Kentucky and Tennessee are positively related to mortality rates. The statistically insignificant effect of Appalachia indicates a weak association between the region and mortality rates and is consistent with the results of thematic and LISA cluster maps.

5. DISCUSSION AND CONCLUSIONS

The application of thematic mapping, ESDA, OLS regression, and spatial regression reveal distinct patterns of mortality and its relationships with particular subregions within central Appalachia. Total and heart-related mortality by sex have high levels of spatial autocorrelation and manifest complex spatial patterns. All results contradict the association between Appalachia and high mortality rates. The clusters of both high and low mortality rates straddle Appalachian borders, except in the northeastern border between West Virginia and Virginia. In other words, while Appalachia is generally associated with high mortality rates, the pattern is highly variable. Appalachia's politically-defined boundaries only weakly correlate with high mortality rates, and clusters of high rates are scattered both within and outside Appalachia.

In contrast, all analyses support the association between some states and high or low mortality rates. Virginia differs from the other states in manifesting consistently low mortality rates. North Carolina manifests a high degree of rate heterogeneity, with the highest rates near the coast and the lowest in the west. West Virginia has higher rates than Virginia has and is located entirely within Appalachia, but it does not stand out with clusters of high or low mortality rates. The only area in West Virginia with somewhat raised mortality rates is along the Kentucky border. Tennessee is weakly associated with high mortality rates, but the distribution within the state is highly variable. Kentucky consistently manifests the highest levels of mortality. Eastern Kentucky is always the largest cluster of counties with high rates, but rates throughout the state are generally higher than in adjacent states. In addition, this analysis identifies the rural areas of central and western Kentucky as having clusters of counties with high mortality rates. This pattern of association with states suggests that differences in state-level policies are important influences on the spatial pattern of mortality in this region. In addition, the strong consistent association between poverty and mortality suggests that economic development and associated strategies may be key factors driving the observed patterns.

I am directing future analyses at overcoming the limitations of the present study. For instance, describing the state-bounded nature of Kentucky's mortality rates entails adding the northern and western borders to the analysis. Further exploration of mortality by additional causes will require simultaneous rate calculation and smoothing. Finally, this research must turn toward identifying the characteristics and policies driving state-bounded mortality.

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