Mortality Disparities in Appalachia

Reassessment of Major Risk Factors

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Objective: To determine the predictive value of coal mining and other risk factors for explaining disproportionately high mortality rates across Appalachia. **Method:** Mortality and covariate data were obtained from publicly available databases for 2000 to 2004. Analysis employed ordinary least square multiple linear regression with age-adjusted mortality as the dependent variable. **Results:** Age-adjusted all-cause mortality was independently related to Poverty Rate, Median Household Income, Percent High School Graduates, Rural–Urban Location, Obesity, Sex, and Race/Ethnicity, but not Unemployment Rate, Percent Uninsured, Percent College Graduates, Physician Supply, Smoking, Diabetes, or Coal Mining. **Conclusions:** Coal mining is not per se an independent risk factor for increased mortality in Appalachia. Nevertheless, our results underscore the substantial economic and cultural disadvantages that adversely impact health in Appalachia, especially in the coal-mining areas of Central Appalachia.

The Appalachian region, as currently defined by the Appalachian Regional Commission (ARC), is comprised of 420 contiguous counties in 13 states stretching from New York to Mississippi.[1] (The numbers of ARC counties has increased from an initial 360 as a result of periodic acts of Congress. There were 399 counties in 1991, 406 counties in 1998, 410 counties in 2002, and 420 counties since 2008.) Encompassing an area of 205,000 square miles, the region overlaps and extends beyond the less sharply demarcated cultural region known as Appalachia. It is home to about 25 million people. For research and other purposes, the region is often divided into five geographic subregions of relatively homogeneous characteristics (eg, topography; demographics) as shown in Fig. 1. Appalachian Regional Commission, a regional economic development agency, was created in 1965 by Congress in recognition that Appalachia suffered disproportionately poor socioeconomic conditions.[2]

It is also well recognized that Appalachians suffer disproportionately poor health and increased risks of adverse health outcomes compared with the rest of the nation.[3,4] For example, the Appalachian region suffers higher rates of total and premature mortality (mortality in persons aged 35 to 64 years),[4,5] heart disease and cardiac mortality,[6–8] cancer incidence[9] and cancer mortality,[10] stroke mortality,[11] chronic pulmonary disease,[5] obesity,[12] and diabetes.[12–14] In the view of many epidemiologists and public health researchers, Appalachia is characterized by "increased chronic disease burden, limited access to health care, and elevated rates of behavioral risks."[15]

Significant health disparities have also been documented within the region, with deficits most consistently found in central and southern Appalachia. Figures 2 to 5 show the regional distributions of county-level premature mortality due to all causes, cancer, heart disease, and stroke. High rates of all-cause mortality are concentrated in eastern Kentucky, southern Ohio, western Virginia, southern West Virginia, northern Alabama, and Mississippi.[4] Cardiac-related death rates are generally higher in rural areas,[8] with highest rates of premature mortality in central and southern Appalachia, particularly eastern Kentucky.[5] Premature cancer mortality is dominated by high rates in the Appalachian counties of Kentucky, Ohio, and West Virginia.[5] In eastern Kentucky, mortality rates for total cancer, lung cancer, and cervical cancer are up to 36% greater than overall Appalachian rates and up to 50% greater than corresponding US rates.[10]

Such disparities impose enormous burdens on the people of Appalachia and their health care and social service systems. As discussed later, a variety of risk factors (eg, age, sex, race, income, and education) have been associated with specific outcomes, but those factors do not fully explain the disparities. It has been proposed that health disparities in Appalachia are due to "highly localized" factors: "health disparities ... result from a combination of factors that are unique to each local area."[4] The public health policy implications of such localized factors are potentially much different from those that apply to more systematic barriers to health.

A recent series of ecological studies by researchers at West Virginia University (WVU) has suggested that age-adjusted Appalachian county mortality rates are independently related to the presence of coal mining, but the nature of that relationship was uncertain.[16–18] Increased mortality rates were apparently not due to occupational exposures and observed mortality patterns differed between Appalachian coal-mining counties and coal-mining counties outside Appalachia. For example, county-level lung cancer mortality was elevated in Appalachian, but not in non-Appalachian coal-mining areas.[18] The WVU authors proposed that observed health disparities in residents of Appalachian mining areas might be attributed to a "coal mining–dependent economy,"[16] or to "pollution" and the "environmental impacts of Appalachian mining,"[17,18] or to "additional behavioral or demographic characteristics not captured through other covariates."[18]

To better understand these possibilities, particularly the role of coal mining as an independent risk factor for disparate mortality rates, we undertook a reanalysis of those published studies. Our objective was to determine the predictive value of coal mining and other potentially relevant risk factors for explaining differences in mortality rates across the Appalachian region.
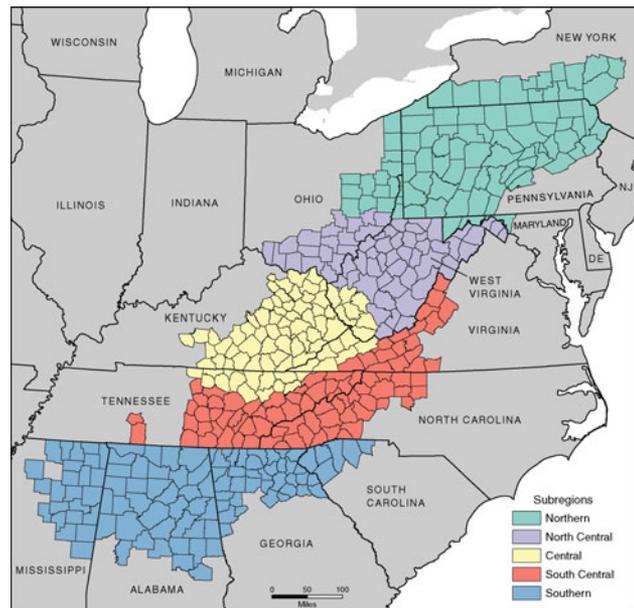
BACKGROUND

A variety of economic measures illustrate how badly the Appalachian region lagged behind other parts of the US in 1965, the year that ARC was founded, and how that status has improved. At that time, 1 in 3 Appalachians lived in poverty, 295 of 360 counties were categorized as "high poverty" (poverty rate >1.5 times US average), and 223 of 360 counties were classified as "economically

FIGURE 1. Geographic subregions in Appalachia. Appalachian counties divided into five geographic subregions of relatively homogeneous characteristics (eg, topography, demographics, economics). Reproduced, with permission, from the Appalachian Regional Commission, November 2009.

distressed."[1,a] By 2008, the poverty rate had declined to 18%, the number of "high poverty" counties had fallen to 116 of 410 counties, and 78 of 410 counties were classified as "distressed." Despite such improvement, however, Appalachian per capita personal income remains about 20% lower than the US average and the region has "fared far worse than the nation" during the recent recession.[19]

Significant economic disparities occur within the region. For example, incomes are relatively high in northern and southern Appalachia, but relatively low in central Appalachia. In 2008, per capita market income for the region overall was 75% of the US average, but only 51% in central Appalachia. Likewise, 57 of the 82 Appalachian counties classified as economically distressed in 2011 were located in the contiguous areas of three central Appalachian states: eastern Kentucky; northern Tennessee; and southern West Virginia.[19] As summarized by ARC, "the central Appalachian region in particular still battles economic distress, with concentrated areas of high poverty, unemployment, poor health, and severe educational disparities."[19] Such economic disparities seem to parallel the characteristic Appalachian landscape: "counties classified by ARC as 'distressed' tend to be the mountainous and isolated counties that most people consider to be Appalachia."[14]

As expected, poorer health status in Appalachia is associated with lower economic status. High rates of premature all-cause mortality, cardiac mortality, and cancer mortality have each been associated with low income, high poverty, high unemployment, and a high percentage of people without health insurance.[5] Similar associations are found when counties are classified by economic status. As a group, economically distressed Appalachian counties had the highest mortality rates from heart disease and stroke.[11] Likewise, prevalence of diabetes increases as economic status declines. In 2007, the prevalence of diabetes was 13% in "economically distressed" Appalachian

counties, more than twice the 6% rate in Appalachian "economic attainment" counties; the corresponding national and regional rates were 8% and 10%, respectively.[14]

Education is also strongly linked with health status; limited education is regarded as a "precursor to poor health."[3,20,21] The region has long been characterized by "severe educational disparities," which persist in some areas.[19] In 2000, the proportion of adults without high school diplomas or equivalents exceeded the US average in 11 of the 13 Appalachian states, and the proportion of those with a college degree was substantially lower. While 24.4% of US adults had college degrees, only 17.7% of Appalachian adults and only 10.2% of those residing in economically distressed Appalachian counties were college graduates.[22–24] Only 18 of 410 Appalachian counties had a higher percentage of college graduates than the national average; most were the homes of large universities. In general, the counties with lowest educational attainment were "concentrated in central Appalachia, especially in the mining regions," where health status is generally worst.[23]

In addition, unhealthy behaviors are more common in the region than in the rest of the nation.[15,25,26] For example, Appalachians have a higher prevalence of tobacco use than does the US population.[25] Five Appalachian states rank among the eight highest for smoking prevalence,[27,28] and smoking rates are higher in the Appalachian counties and Labor Market Areas than the non-Appalachian counties and Labor Market Areas of those five states.[4,29,b] High rates of smoking cluster in central Appalachia, notably in eastern Kentucky and West Virginia where smoking rates are the nation's highest.[4,9,27] In those areas, high smoking rates coincide with the nation's highest lung cancer rates, with similar patterns seen for other tobacco-related cancers.[9,30,31]

Lack of physical exercise and poor eating habits are two other behaviors that adversely impact regional health. Compared with the US population, residents of southern and central Appalachia are less likely to engage in recommended levels of physical activity and more likely to have no physical activity during leisure time.[25,32] Residents of rural Appalachia are also more likely to consume less nutritious, more energy-dense diets.[14,25] Because inactivity and poor diet are risk factors for obesity, and because inactivity, poor diet, and obesity are all risk factors for diabetes, it is not surprising that obesity and diabetes are more prevalent in Appalachia. Likewise, physical inactivity, poor diet, and obesity are risk factors likely to contribute to the increased incidence of cancer in rural Appalachia.[26,33]

In 1997, the prevalence of obesity (body mass index $>30 kg/m^2$) in Appalachian counties ranged from 10.2% to 27.6% among men and 7.8% to 25.3% among women. High rates of obesity clustered in eastern Kentucky, southern West Virginia, north-central Pennsylvania, and southeast Ohio.[34] In 2007, the highest prevalence rates of obesity and diabetes in the United States were mainly found in the Appalachian counties of West Virginia, eastern Kentucky, and northern Tennessee.[12]

Nevertheless, such risk factors, at least as measured by traditional epidemiologic variables, seem insufficient to fully explain the region's health disparities. For example, after accounting for a variety of covariates (eg, age, sex, race, education, income, smoking, obesity, and physical activity), residents of economically distressed counties in Appalachia had a statistically significant 33% greater risk of having diabetes than did residents of non-Appalachian counties; by contrast, risks did not differ between non-Appalachian counties and the Appalachian counties not classified as distressed.[14]

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[a]According to ARC, a county is "economically distressed" if it ranks in the worst 10% of US counties for three-year average unemployment rate, per capita market income, and poverty rate. By contrast, a county has achieved "economic attainment" if it ranks in the best 10% of US counties.[71]

[b]The US Department of Labor defines Labor Market Area (LMA) as "an economically integrated geographic area within which individuals can reside and find employment within a reasonable distance or can readily change employment without changing their place of residence." In Appalachia, non-metropolitan LMAs are generally identical to counties.[72]

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Some of the health disparities not accounted for by the traditional risk factors may be attributed to the geographic isolation that characterizes rural Appalachia. Such isolation adversely impacts regional health status by creating logistical barriers to health care access and by limiting employment opportunities, thus contributing to poverty and lack of health insurance.[25] For such reasons, residents of rural Appalachia generally utilize fewer preventive health services such as routine cancer screening.[26,35–38] Geographic isolation, which leads to fewer local medical and other support resources, is also a likely explanation for the increased mortality rates from coronary heart disease in rural versus metropolitan Appalachian communities.[8] Other data suggest that rural Appalachians with cancer have less access to comprehensive diagnostic and treatment services.[39] And by limiting access to health care services and producing physician shortages, the rural geography has seemingly caused an adverse impact on Appalachia's "diabetes problem."[40]

Cultural and social factors associated with residence in distressed areas are also likely to adversely impact health. Factors suggested as relevant include "Appalachian cultural beliefs such as fatalism," which reinforces poor health behaviors and discourages seeking of early health intervention and medical advice. In addition, high rates of smoking lead to increased exposure to second-hand smoke.[14,18] Local social conditions also influence dietary habits, and thereby health. Rural Appalachia is distinguished by a relative lack of full-service grocery stores and fruit-and-vegetable markets; residents of such "food deserts" tend to shop in stores with fewer nutritional choices and have less nutritious diets.[14,34,41,42]

METHODS

Design

This study retrospectively investigated all-cause mortality rates for residents of Appalachia during the years 2000 to 2004. Mortality and covariate data were obtained from publicly available databases. The time period considered and the data utilized were selected to allow for analyses that closely resembled those described in the WVU studies.[16–18] Data were collected to represent the same time period (2000 to 2004) as much as possible given data availability, but the actual time periods corresponding to specific variables were not identical. Because the WVU analyses differed from study to study, we choose to incorporate the least complex of those alternative approaches for our basic model. The following discussions of Data and Analysis explain that process in detail.

Data

Mortality

Mortality data were obtained from the Centers for Disease Control and Prevention.[43] Reported data described county-level mortality rates age adjusted to the 2000 US standard population. We utilized all-cause mortality for all age groups.

Demographic Data

We obtained county-level demographic data from the 2005 Area Resource File.[44] The percent men population was calculated as the arithmetic mean for the years 2000 to 2003. The percentages of the population who were white, African American, Native American, non-white Hispanic, and Asian American were determined for the year 2000.

Economic Status

Four measures of economic status have been associated with mortality rates in Appalachia: median household income; poverty rate; unemployment rate; and rate of health insurance.[5] Each was considered in at least 1 of the 3 WVU analyses. We obtained county-level economic data from the Area Resource File.[44] Median Household Income and Poverty Rate were determined as the arithmetic means for the years 2000 to 2002. Unemployment Rate (persons aged ≥16 years) and Percent Uninsured were obtained for the year 2000.

Education

County-level rates of high school graduates and college graduates were calculated using ARC data for the year 2000.[45] The number of persons with a high school diploma or higher (Percent High School Graduates), and the number of persons with a college diploma or higher (Percent College Graduates) were each divided by the number of persons aged 25 years or older.

Location

The location type of each county was characterized using the US Department of Agriculture (USDA) nine-point rural–urban classification scheme, which codes metropolitan and nonmetropolitan counties by degree of urbanization, adjacency to metro areas, and population size of urban areas.[46] (For example, "Code 1" = "counties in metro areas of 1 million population or more"; "Code 5" = counties with "urban population of 20,000 or more, not adjacent to a metro area", and "code 9" = counties that are "completely rural or <2500 urban population, not adjacent to a metro area".) We obtained county-specific rural–urban continuum codes from the Area Resource File.[44] We divided the USDA rural–urban continuum codes into three categories: Metropolitan (codes 1 to 3), Micropolitan (codes 4 to 7), and Rural (codes 8 to 9).

Access to Health Care

County-specific physician supply was used as a measure of access to health care. Data for the number of active medical doctors (MDs) and osteopathic doctors (DOs) per 1000 population were obtained from the Area Resource File.[44] Two of the WVU studies used "number of active MDs and DOs per 1000 population,"[17,18] whereas the third included "physician supply" not otherwise defined.[16] In our analyses, Physician Supply indicates the number of active MDs and DOs per 1000 population.

Smoking

Rates of current smokers were obtained from the Centers for Disease Control and Prevention Behavioral Risk Factor Surveillance System (BRFSS)[28] supplemented with smoking rates available from state public health department Web sites. County-level data were available for 54 Appalachian counties, of which 9 were reported at the level of metropolitan statistical areas. For the other 366 counties, smoking rates were available as the means for each of 84 subgroups of contiguous counties. When available, we used rates averaged for the years 2002 to 2004; otherwise, we used data for the year(s) closest to that time period. (Smoking data were available for the following years for each state: Alabama: 2009–10; Georgia: 2000–03; Kentucky: 2002–04; Maryland: 2000–02; Mississippi: 2004; New York: 2003; North Carolina: 2002–04; Ohio: 2002; Pennsylvania: 2002–04; South Carolina: 2002–04; Tennessee: 2005; Virginia: 2007; West Virginia: 2001–05.)

Obesity and Diabetes

We obtained county-level data for obesity and diabetes from the National Diabetes Surveillance System for the year 2004.[47] Obesity Rate indicates the proportion of adults aged 20 years or older with body mass index 30 kg/m^2 or more. Diabetes Rate indicates the proportion of adults aged 20 years or older with diagnosed diabetes.

Coal Mining

County-specific coal production data were obtained from the Energy Information Administration.[48] In our analyses, we divided
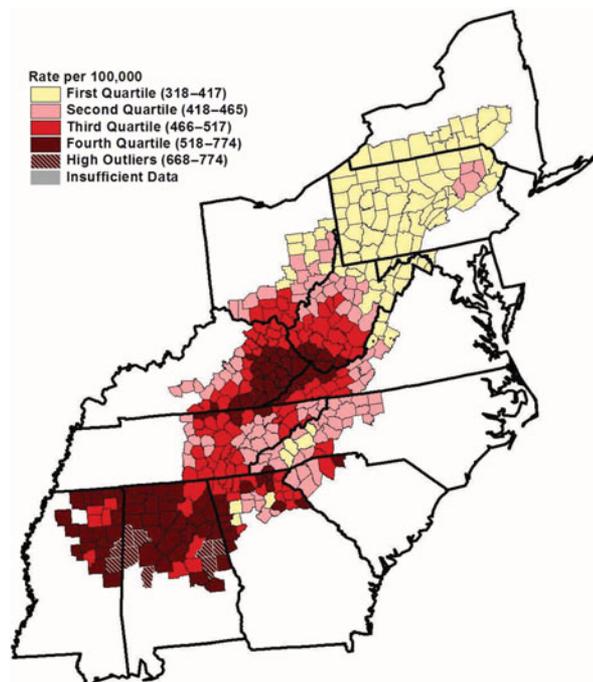
Figure 2. All-cause premature mortality (1995– 2001).
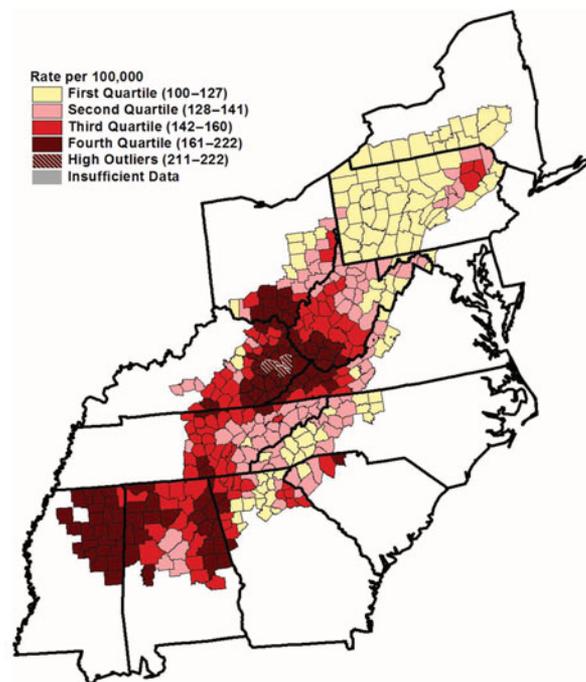
FIGURE 4. Heart disease premature mortality (1995–2001).
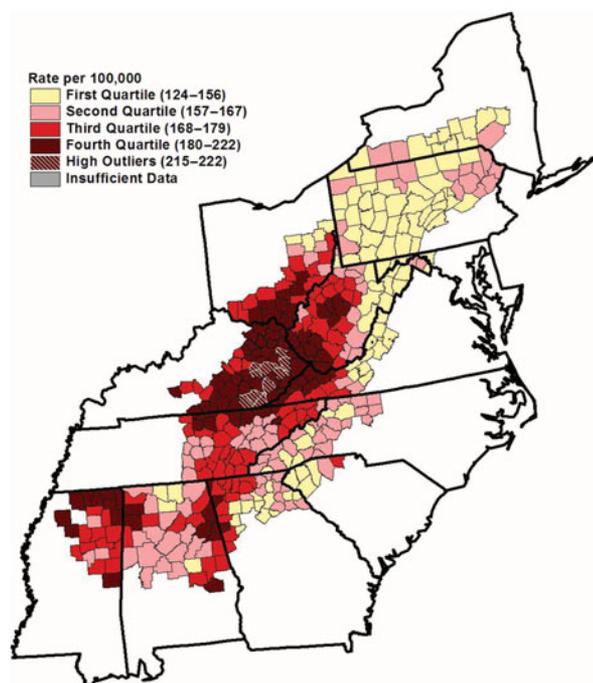
FIGURE 3. All-site cancer premature mortality (1995–2001).
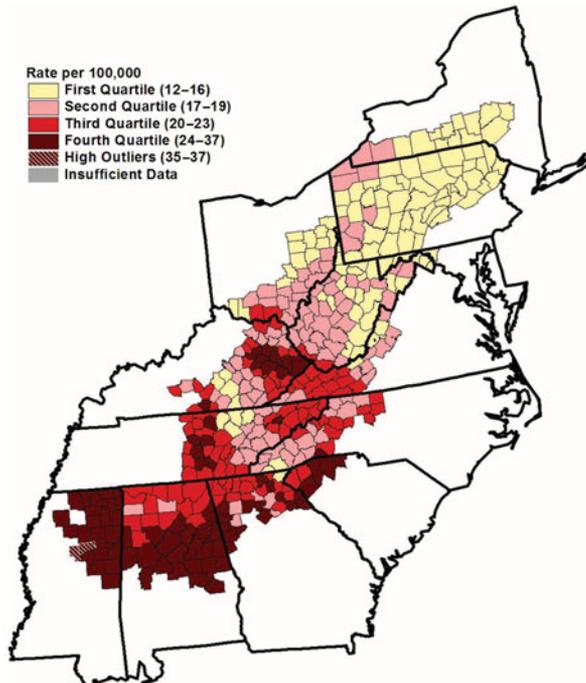
FIGURE 5. Stroke premature mortality (1995–2001).

FIGURES 2–5. Premature mortality in Appalachia (1995–2001). These four maps show the distribution of county-level premature mortality rates for 1995–2001, standardized to 2000 census. "High Outlier" identifies counties with death rates greater than the 75th percentile plus 1.5 times the interquartile range. Adapted from Halverson and Bischak[5]; reproduced, with permission, from the Appalachian Regional Commission.
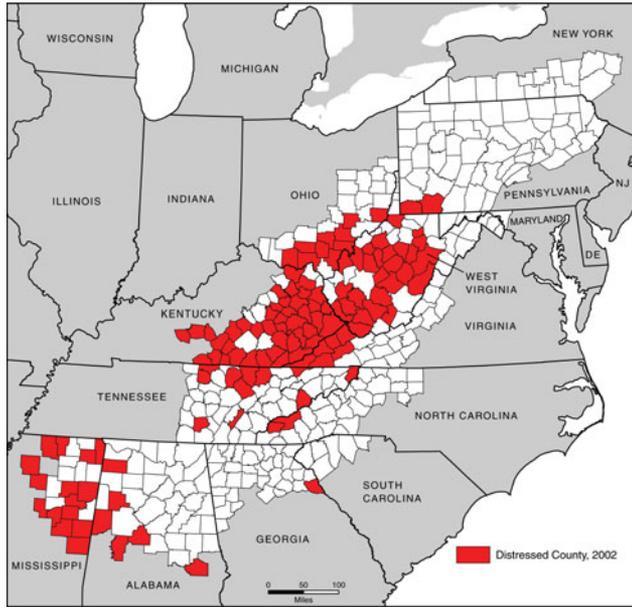
FIGURE 6. Appalachian Regional Commission–designated distressed counties (2002). A county is designated as "economically distressed" if it ranks in the worst 10% of US counties for 3-year average unemployment rate, per capita market income, and poverty rate. Reproduced, with permission, from the Appalachian Regional Commission, June 2002. Data sources: US Bureau of Labor Statistics, LAUS, 1997–1999; US Bureau of Economic Analysis, REIS, 1998; and US Census Bureau, STF3A, 1990.
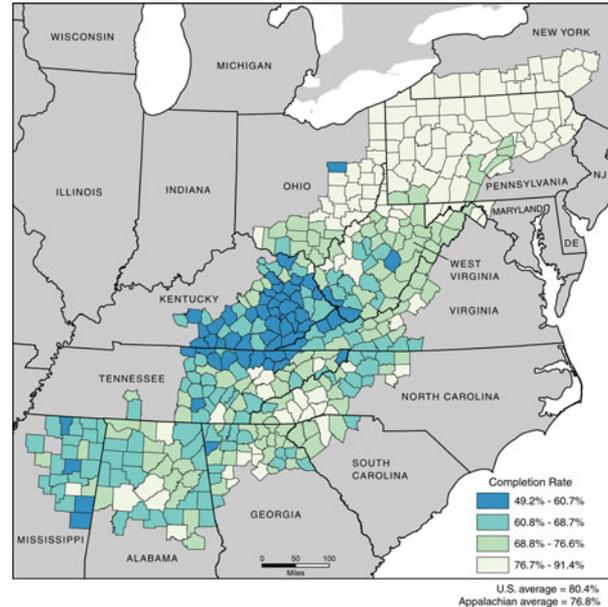
FIGURE 8. High school completion rates in Appalachia (2000). County-level percentages of adults, 25 years and older, completing 12 years or more of school. Reproduced, with permission, from the Appalachian Regional Commission, October 2008. Data source: US Census Bureau, 2000 Census, SF3. Data classification scheme: Natural Breaks.

FIGURE 7. Poverty rates in Appalachia (2000). County-level ratios of the persons below poverty level to the total number of persons for whom poverty stat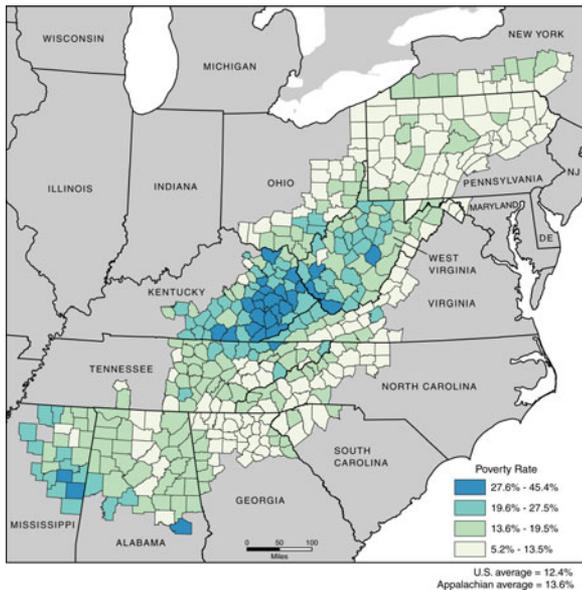us has been determined. Reproduced, with permission, from the Appalachian Regional Commission, October 2008. Data source: US Census Bureau, 2000 Census, SF3. Data classification scheme: Natural Breaks.
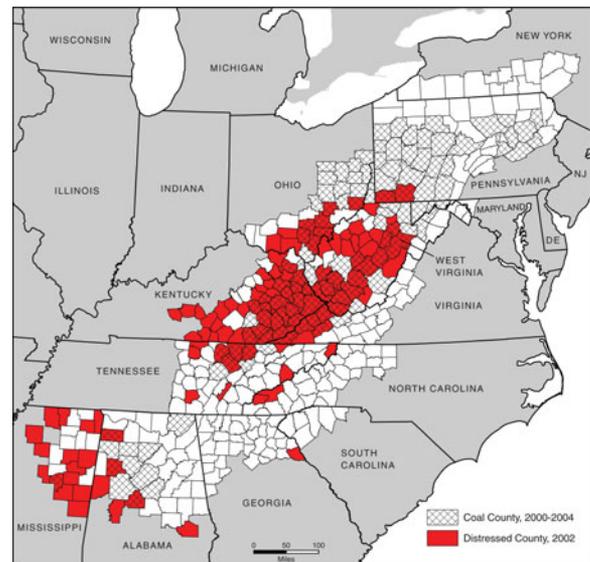
FIGURE 9. Appalachian Regional Commission–designated distressed counties (2002) and coal-producing counties (2000–2004). Counties were designated as "coal producing" if any amount of coal was mined during 2000–2004. Reproduced, with permission, from the Appalachian Regional Commission, September 2011. Data sources: US Department of Energy, EIA, 2011; US Bureau of Labor Statistics, LAUS, 1997–1999; US Bureau of Economic Analysis, REIS, 1998; and US Census Bureau, STF3A, 1990.

Appalachian counties into two groups based on whether they produced coal during 2000 to 2004 and we also grouped coal-producing counties into those above (High) and below (Low) the median coal production level for Appalachian counties during that time period.

Analysis

The data were analyzed using SAS 9.2 (SAS Institute, Cary, NC).[49] We conducted ordinary least square multiple linear regression with age-adjusted mortality as the dependent variable. Our basic regression model ("Basic Model") paralleled the WVU analyses, but we considered only the 420 Appalachian counties, and we did not include coal mining–related variables or the "dichotomous Southern variable . . . created to capture regional effects that partially overlap with Appalachia."[18] The model included the following independent variables:

- Percent Men
- Race/Ethnicity Rates
- Poverty Rate
- Percent High School Graduates
- Percent College Graduates
- Rural–Urban Category
- Physician Supply
- Smoking Rate

Next, we added additional independent variables into the basic model and evaluated their explanatory power by means of partial F tests. Partial F tests are used to determine whether the addition of one or more variables to an already specified model significantly decreases the unexplained variance of the model.[50] When that occurs, addition of the variable is said to have significantly improved the model's fit to the observed data. The partial F test is also known as Type 3 test for fixed effects when the addition of only one more variable is contemplated.

Additional variables were added one at a time to the Basic Model, regression analyses were performed, and the results compared with the regression results for the Basic Model without that additional variable. If partial F tests indicated that inclusion of the variable led to significantly improved model fit, the variable was retained in an "Expanded Model." Alternatively, if including a variable did not significantly improve the model, it was excluded. This process was repeated using Expanded Models in place of the Basic Model, until all variables had been evaluated. The following is a list of the additional independent variables that were tested in this way, listed in the order in which they were added:

- Median Household Income
- Unemployment Rate
- Percent Uninsured
- Obesity Rate
- Diabetes Rate
- Coal Mining (Yes/No)
- Coal Mining (High/Low/None)

RESULTS

The results of ordinary least squares multiple linear regression analysis of the Basic Model are presented in Table 1. These findings indicate that higher age-adjusted all-cause mortality rate was independently related to Poverty Rate, Percent High School Graduates, Rural–Urban Location, and Demographic variables including Sex and Race/Ethnicity rates. Mortality Rate was not significantly related to Percent College Graduates, Physician Supply, or Smoking Rate.

We then evaluated whether inclusion of additional variables would significantly reduce the unexplained variance of the Basic Model, thus improving its fit to the age-adjusted mortality data. Table 2 presents the results of this sequential testing, indicating F score, P value, and conclusions for each of the seven variables. Inclusion of Median Household Income significantly improved the Basic Model ($P < 0.0001$) and it was retained in an "Expanded Model." Likewise, Obesity Rate significantly improved the Expanded Model ($P = 0.0022$), and it was retained in a "Further Expanded Model." By contrast, no improvements resulted from the addition of Unemployment Rate ($P = 0.6852$), Percent Uninsured ($P = 0.3036$), Diabetes Rate ($P = 0.3704$), Coal Mining: Yes/No ($P = 0.6003$), or Coal Mining: High/Low/None ($P = 0.1047$), and they were excluded.

Table 3 presents the results of ordinary least squares multiple linear regression analysis of the Further Expanded Model. The variable Coal Mining: Yes/No has been included to demonstrate its lack of statistical significance when added to the model. These findings indicate that higher age-adjusted all-cause mortality rate was independently related to Poverty Rate, Median Household Income, Percent High School Graduates, Rural–Urban Location, Obesity Rate, and Demographic variables including Sex and Race/Ethnicity rates. The relationship between Mortality Rate and Percent College Graduates was nearly significant ($P = 0.0814$), but Mortality Rate was not significantly related to Physician Supply, Smoking Rate, or Coal Mining: Yes/No.

We also performed regression analyses of the Further Expanded Model after adding each of the excluded variables (Unemployment Rate, Percent Uninsured, Diabetes Rate, Coal Mining: Yes/No and Coal Mining: High/Low/None). First, we added a variable and ran the model, and then we removed that variable and added the next variable and repeated the process so that all variables were individually tested. Then we included all variables in the model at one time (but only one of the Coal Mining variables was included at any time). Adding each or all of those excluded variables did not significantly change the model's parameter estimates or their P values (data not shown); hence, all inferences remained the same.

DISCUSSION

Appalachians suffer disproportionately poorer health and significantly higher mortality rates than the rest of the nation.[3–5] In general, the Appalachian counties with poorest health are also the most economically distressed, the least educated, and those with the most limited access to social and medical services. In addition, residents of those counties demonstrate generally higher rates of risky behaviors, for example, higher smoking rates, more prevalent obesity, less physical activity, less nutritious diets, and less use of preventive health services. Notably, these often rural, isolated counties include many of the most productive coal-mining areas in Appalachia.[51]

Earlier efforts to understand and address the sources of such health disparities have identified a number of independent risk factors associated with specific health outcomes, but have not fully explained the disparities. Some have proposed that health disparities in Appalachia are due in part to factors "unique to each local area."[4] A recent series of ecological studies has suggested that the presence of coal mining is such a "local" factor, which is independently related to age-adjusted mortality rates, although the nature of that relationship is uncertain.

To better understand that relationship, we studied all-cause mortality rates for Appalachian residents during 2000 to 2004. Mortality and covariate data were selected to create a Basic Model that closely resembled the models employed in the UWV ecological studies, but did not include coal mining. As seen in Table 1, the regression analysis of that Basic Model indicated that increased mortality rate was significantly associated with greater poverty, lesser educational

TABLE 1. Basic Model: Ordinary Least Squares Multiple Linear Regression Model; Age-Adjusted All-Causes Mortality Rate

Data Category	Basic Model			
	Variable	Coefficient	SE	*P*
	Intercept	5179.71	1101.18	**<0.0001**
Economic status	*Poverty Rates*	7.99	1.28	**<0.0001**
Education	*Percent High School*	− 497.87	87.92	**<0.0001**
	Percent College	− 174.43	117.46	0.1383
Location	*Rural–Urban Category*	− 30.54	5.97	**<0.0001**
Access to health care	MDs and DOs per 1000	2.56	2.61	0.3285
Smoking	Smoking Rate	90.31	100.38	0.3688
Demographics	*Percent Men*	− 805.75	320.29	*0.0123*
	Percent White	− 35.49	11.00	*0.0014*
	Percent Black	− 35.67	10.98	*0.0013*
	Percent Asian	− 41.35	14.71	*0.0052*
	Percent Native American	− 33.70	11.94	*0.0050*
	Percent Latin	− 20.48	6.72	*0.0025*

Bold and italicized indicates statistically significant variables.
DO, osteopathic doctor; MD, medical doctor.

TABLE 2. Explanatory Power of Additional Independent Variables, With Sequential Addition of Significant Variables to the Basic Model, as Evaluated Using Partial F Test

Comparisons	Numerator *df*	Denominator *df*	F Score	*P*	Conclusion
(1), Basic Model					
(1) vs (2) [Basic Model + Income]	1	406	15.220	0.0001	**Retain income in model**
(2) vs (3) [Basic Model + Income + Unemployment Rate]	1	405	0.165	0.6852	Unemployment Rate does not improve model; **Exclude**
(2) vs (4) [Basic + Income + Percent Uninsured]	1	405	1.065	0.3036	Percent Uninsured does not improve model; **Exclude**
(2) vs (5) [Basic + Income + Obesity]	1	405	9.483	0.0022	**Retain Obesity in model**
(5) vs (6) [Basic + Income + Obesity + Diabetes]	1	404	0.804	0.3704	Diabetes Rate does not improve model; **Exclude**
(5) vs (7) [Basic + Income + Obesity + Mining (Yes/No)]	1	404	0.275	0.6003	Mining (Yes/No) does not improve model; **Exclude**
(5) vs (8) [Basic + Income + Obesity + Mining (High/Low/None)]	2	403	2.269	0.1047	Mining (High/Low/None) does not improve model; **Exclude**

attainment, rural location, and demographic factors including sex and race. No significant associations were seen for smoking or physician supply.

We then expanded that Basic Model. First, we considered the inclusion of three additional economic measures (Median Household Income, Percent Unemployed, and Percent Uninsured) as independent variables. Those three measures, along with Poverty Rate, are generally correlated, but they are nonidentical and reflect different aspects of socioeconomic status and economic distress.[5,52,53] All four have been independently associated with Appalachian mortality rates.[4,5] The WVU model did not include Median Household Income, Percent Unemployed, or Percent Uninsured.

The inclusion of Median Household Income significantly improved the model's fit to the observed data and it was included in an Expanded Model. By contrast, neither of the two other economic variables significantly reduced the unexplained variance of the Ex-

panded Model (ie, Basic Model plus Median Household Income); hence, neither was retained in the model.

We next considered whether adding Obesity Rate and Diabetes Rate would improve the Expanded Model's explanatory power. Both are important risk factors for mortality. The World Health Organization has determined that "overweight and obesity" is the fifth leading risk factor for deaths worldwide,[54] and Centers for Disease Control and Prevention recognizes diabetes as the seventh leading cause of death in the United States.[55] Obesity is also seen as a more important risk factor for chronic disease than either smoking or poverty.[56,57] Neither Obesity Rate nor Diabetes Rate was included in the WVU analytical models.

In our analyses, addition of Obesity Rate significantly improved the Expanded Model and it was retained in a Further Expanded Model (ie, Basic Model plus Median Household Income plus Obesity Rate). By contrast, adding Diabetes Rate to that model yielded no significant improvement and it was excluded.

TABLE 3. Further Expanded Model: Ordinary Least Squares Multiple Linear Regression Model; Age-Adjusted All-Causes Mortality Rate. Coal Mining (Yes/No) Has Been Included for Demonstration Purposes, but Is Not a Component of the Model

Data Category	Variable	Coefficient	SE	*P*
	Intercept	4977.06	1076.63	**<0.0001**
Economic status	*Poverty Rates*	10.96	1.90	**<0.0001**
	Median Household Income (per $1000)	4.86	1.27	**0.0001**
Education	*Percent High School*	− 510.44	90.52	**<0.0001**
	Percent College	− 222.60	127.42	0.0814
Location	*Rural–Urban Category*	− 20.55	6.17	**0.0010**
Access to health care	MDs and DOs per 1000	2.98	2.59	0.2500
Smoking	Smoking Rate	52.67	98.61	0.5935
Obesity and diabetes	*Obesity Rate*	5.96	1.97	**0.0027**
Demographics	*Percent Men*	− 931.40	316.61	**0.0035**
	Percent White	− 36.39	10.74	**0.0008**
	Percent Black	− 37.23	10.71	**0.0006**
	Percent Asian	− 41.38	14.38	**0.0042**
	Percent Native American	− 35.06	11.65	**0.0028**
	Percent Latin	− 21.96	6.56	**0.0009**
Coal mining	Coal Mining (Yes/No)	4.68	8.92	0.6003

Bold and italicized indicates statistically significant variables.

Finally, we considered the effects of including either of the two measures of coal mining in the Further Expanded Model. Neither Coal Mining: Yes/No nor Coal Mining: High/Low/None significantly improved the explanatory power of the model. The findings of this analytical model argue that coal mining is not per se an independent risk factor for increased mortality in Appalachia. By contrast, we found that increased mortality was significantly associated with greater poverty, lower median household income, fewer high school graduates, rural location, obesity rate, and demographic factors including sex and race. Lower college graduate rate was nearly significant. Moreover, we found no significant associations for smoking, physician supply, and diabetes.

It seems surprising that smoking rate was not significantly associated with mortality, given that smoking causes about 20% of US deaths,[58] but similar results were reported in WVU studies.[16,59] This is likely due to limitations of the available data. BRFSS determines current smoking status, not quantity or duration (The relevant BRFSS questions are "Have you smoked at least 100 cigarettes in your entire life?" and "Do you now smoke cigarettes every day, some days, or not at all?.[28]), thus BRFSS data do not capture the substantial dose–response gradient linking smoking and mortality.[60] Also, smoking data were available for only 54 of 420 individual Appalachian counties; for the other 366 counties, the available smoking rate were mean values calculated for each of 84 subgroups of contiguous counties. Thus, Smoking Rate is almost certainly biased by non-differential misclassification, a particular concern in light of evidence that smoking rates are increased in coal-mining areas.[17,18,59] To the extent that such misclassification "biases toward the null", the link between smoking and mortality would be differentially reduced in high-smoking counties. The available data are not adequate to evaluate whether smoking might act synergistically with other environmental pollutants.

Likewise, we were surprised that Diabetes Rate failed to improve the model, but this is likely explained by two factors. First, obesity is a critical risk factor for diabetes and the two are well correlated. Risk of diabetes, for example, was increased up to 11-fold in Medicare recipients with a history of midlife obesity.[61] Thus Diabetes Rate may add little explanatory value not associated with Obesity Rate. Second, BRFSS self-reported diabetes status is likely to misclassify a substantial proportion of the population because more than 27% of adults with diabetes in the United States have "undiagnosed diabetes."[62] Such misclassification would likely have greatest impact in the economically distressed Appalachian counties where reported diabetes rates are generally higher and utilization of preventive services generally lower than in other counties. Thus, in those counties apparent associations between diabetes and mortality are probably understated.

Lack of a significant association between Physician Supply and mortality rate is also notable. One explanation is that the number of physicians is "just one factor within complex environments," which include other health care workers and a variety of health care delivery systems: "Higher physician supply per se does not amount to better access, quality, or outcomes."[63] Some studies report that an increased supply of primary care physicians, but not specialists is associated with reduced mortality.[64] Reanalysis of their data, however, suggested that benefits were region-clustered and less likely to occur in rural populations.[65] Finally, there is no standard approach to quantifying the supply of primary care providers using secondary data sets; it is likely that some specialists will be misclassified, while nurse practitioners and physician assistants are ignored.[65]

We doubt that the differences between our findings and those of the WVU studies are due to the ways in which covariates were selected and defined. We chose time periods, variables, and data to closely resemble those studies. In three cases, the WVU studies incompletely or inconsistently defined their covariates. In those cases, we chose the least complex alternative for our model; thus, we used covariates that were similar, but not necessarily identical. For example, the WVU studies defined Physician Supply as the number of active MDs and DOs per 1000 population. Some results were also reported for "primary care physicians," a category not specifically contained in the 2005 Area Resource File and

no explanation was given as to how "primary care physicians" was defined. We defined Physician Supply as the number of active MDs and DOs per 1000 population; we did not differentiate "primary care physicians."

A second case involves the rural–urban continuum. Two WVU studies included the nine-point USDA continuum scale,[16,17] while the third study, citing concerns for nonlinearity, recoded the scale into three categories ("metropolitan," "micropolitan," and "rural").[18] Nevertheless, that study did not actually define the categories. To understand how these categories were structured, we reviewed other studies by those researchers who included the USDA scale, but found the scale used in still other ways. One study defined only two categories, "metropolitan" (codes 1 to 3) and "nonmetropolitan" (codes 4 to 9), but then treated "rural" and "nonmetropolitan" as equivalent terms: "The terms rural and nonmetropolitan will be used interchangeably in this study."[66] A second study coded "metropolitan" status as a "five-level variable," but no further details were provided.[67] A third[68] included "rural–urban setting" as a covariate that was not defined. Our analyses included three explicitly defined categories that seem consistent with the USDA scheme and the least complex of the WVU approaches.[18]

The third case involves coal mining. The WVU studies each defined different coal-mining categories. One defined coal-mining areas as "counties with any amount of coal mining" during 1994 to 2005; some analyses also grouped coal-mining counties into those above and below the median production level.[16] A second study defined three groups of counties based on total 2000 to 2004 coal production: more than 3 million tons; less than 3 million tons; and no production.[18] For some analyses, counties with more than 3 million tons of production were compared with all other counties combined and "per capita coal production" (calculated relative to the 2000 census) was also included in those analysis. The third study also defined three groups of counties on the basis of total 2000 to 2004 coal production, but groups were defined differently: more than 4 million tons; less than 4 million tons; and no production.[17] Our approach was similar to the first of those WVU studies, but we considered the time span considered in the latter two studies. Our analysis divided counties into two groups based on whether any amount of coal was mined during 2000 to 2004, and coal-producing counties were further grouped into those above and below the median production level for Appalachian counties during that time period.

Our Expanded Model indicates that coal mining is not per se the cause of increased mortality in rural Appalachia. On the contrary, our results underscore the substantial economic and cultural disadvantages that adversely impact the health of many area residents. Particularly in the coal-mining areas of central Appalachia, there is a potent combination of greater economic distress, lesser educational attainment, decreased access to health care, limited availability of nutritious foods, higher rates of behavior-related risks such as obesity and smoking, and decreased use of preventive health services. The conjunction of such factors and their adverse effects can be seen by comparing Figs. 2 to 5, which show the geographical distributions of various county-level mortality rates, and Figs. 6 to 9, which show the distributions of county-level poverty rate, economic distress, percent high school graduates, and coal mining.

Such overlapping risk factors and mortality rates illustrate how difficult it can be to disentangle the effects of the cultural environment from those of the physical environment, a difficulty made greater because the two interact. For example, the physical isolation of the mountainous counties that characterize rural Appalachia poses barriers to industrial diversification and broadening of employment options, and also contributes to lower incomes, reduced access to health care services, reduced availability of nutritious foods, and so forth.[14,25] The interplay of geographical isolation, kinship, and health-related behaviors further complicates matters. Rural Appalachia is distinguished by tight-knit social networks,

"cohesive, extended, and geographically connected" kinships, which often extend beyond biological families.[15,69] Such networks can exert significant influence on the behaviors and health of their individual members, as recently documented in the Framingham Study. In that well-studied New England community, risks of becoming obese (ie, the "induction and person-to-person spread of obesity") were predicted by the closeness of social relationships, not by "common exposure to the local environment."[70] Thus, the physical environment (eg, geographical isolation) can foster cultural practices (eg, tight-knit kinships) that promote adverse health outcomes (eg, obesity).

Accordingly, coal mining in Appalachia, an industrial activity associated with rural, mountainous areas, is likely to be geographically associated with a variety of economic and cultural health risk factors. And, for similar reasons, mining is also likely to be geographically associated with a variety of adverse health outcomes. Although our results indicate that mining is not the direct cause of those outcomes, they do not rule out the possibility that mining contributes to the development of the social environments and cultural practices that adversely impact health. This possibility seems most likely in those specific areas where mining is the principal industry. Likewise, our analyses do not rule out the possibility that some specific mining methods may have greater adverse effects than others on the physical environment.

Ultimately, the issue of greatest concern is that Appalachians suffer disproportionately poor health and increased risks of adverse health outcomes compared with the rest of the nation.[3] During the past 50 years, ARC and others have overseen substantial improvements in the well-being of regional residents. Nevertheless, significant shortfalls persist. To eliminate health-related disparities, substantial efforts must be directed at the region's underlying economic and social disparities. To the extent that coal mining is factor in defining the cultural fabric and socioeconomic environment of Appalachian communities, the coal-mining industry must play a role in efforts to increase economic diversity, develop job-creation programs, ensure access to appropriate heath care services, improve educational opportunities, and facilitate access to nutritious foods and diets.

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