BRIEF REPORT

Estimating mortality from coal workers' pneumoconiosis among Medicare beneficiaries with pneumoconiosis using binary regressions for spatially sparse data

Rajib Paul PhD | Oluwaseun Adeyemi MBChB, MPH | Ahmed A. Arif MBBS, PhD

Department of Public Health Sciences, The University of North Carolina at Charlotte, Charlotte, North Carolina, USA

Correspondence
Rajib Paul, Department of Public Health Sciences, University of North Carolina at Charlotte, 9201 University City Blvd, Charlotte, NC 28223, USA.
Email: rajib.paul@uncc.edu

Abstract

Background: Coal workers' pneumoconiosis (CWP) is an occupational lung disease due to inhalation of coal dust. We estimated mortality from CWP and other pneumoconioses among Medicare beneficiaries.

Methods: We used the 5% Medicare Limited Claims Data Set, 2011–2014, to identify patients diagnosed with ICD-9-CM 500 (CWP) through 505 (Asbestosis, Pneumoconiosis due to other silica or silicates, Pneumoconiosis due to other inorganic dust, Pneumonopathy due to inhalation of other dust, and Pneumoconiosis, unspecified) codes. We applied binary regression models with spatial random effects to determine the association between CWP and mortality. Our inferences are based on Bayesian spatial hierarchical models, and model fitting was performed using Integrated Nested Laplace Approximation (INLA) algorithm in R/RStudio software.

Results: The median age of the sample was 76 years. In a sample of 8531 Medicare beneficiaries, 2568 died. Medicare beneficiaries with CWP had 25% higher odds of death (adjusted OR: 1.25, 95% CI: 1.07, 1.46) than those with other types of pneumoconiosis. The number of comorbid conditions elevated the odds of death by 10% (adjusted OR: 1.10, 95% CI: 1.09, 1.10).

Conclusion: CWP increases the likelihood of death among Medicare beneficiaries. Healthcare professionals should make concerted efforts to monitor patients with CWP to prevent premature mortality.

KEYWORDS
Bayesian analysis, comorbidity, lung disease, occupational hazard, spatial models

1 | INTRODUCTION

Coal workers' pneumoconiosis (CWP) represents a group of pneumoconiosis that result from accumulated coal dust in the lungs.[1] It is a chronic respiratory disease that manifests initially as an asymptomatic discoloration of the lungs (black lung or anthracosis), progresses to symptomatic massive fibrosis of the lungs, ultimately leading to death from respiratory causes.[2] A nonreversible pathologic process further characterizes this disease, even in the absence of continued exposure to coal dust.[1,3,4] The recent resurgence of CWP,[5,6] which threatens to

---

This study was conducted at the University of North Carolina at Charlotte.

undermine three decades of continued decline in prevalence rates of CWP,[4] has renewed the occupational health concern among coal workers.[7] As of 2017, the prevalence of CWP among US coal miners with 25 years or more of tenure exceeds 10%[8] compared to 2.1% in 1990.[4] Additionally, recent studies have identified clusters and hotspots of CWP in Kentucky, Virginia, West Virginia, and Central Appalachia.[4,5,9]

Studies have demonstrated an increased risk of mortality from CWP among coal miners.[10–12] Underground miners with CWP in the Czech Republic have a 10% excess mortality than underground miners without CWP.[10] In China, where about 60% of electricity is generated from coal,[13] CWP mortality rates increased from 0.4% among those aged 25–29 years to 13.3% among those aged 70 years and older.[14] In contrast, in the United States, mortality rates from CWP have declined from 2.3 per million in 1999 to 0.44 million in 2016,[15] likely due to strict regulatory control on coal dust levels. However, the recent CWP resurgence threatens the progress made in the last 20 years.[16,17] Also, potential life lost due to CWP per decedent increased from 8.1 to 12.6 years during 1999–2016 and it was attributed to the severity and fast progression of CWP.[15]

Conventionally, epidemiological-based estimates of mortality have rightfully relied on nonparametric approaches. While this methodological approach provides suitable risk estimates, CWP is primarily an occupational disease,[18] exhibiting spatial characteristics.[9] Spatial and small area estimators [19] are, therefore, appropriate elements in modeling the mortality risk of CWP. Using this methodology, coupled with a multilevel approach [20] of accounting for county-level and individual-level determinants, serves as a robust technique in estimating the mortality risk associated with CWP. This study, therefore, uses a multilevel binary regression model with spatially sparse dependence to estimate the excess risk associated with CWP mortality among Medicare beneficiaries.

This study has two aims: (1) estimating the individual-level mortality risk and the factors associated with increased mortality from CWP among Medicare beneficiaries with pneumoconiosis in the United States and (2) assessing how the combined individual and county-level factors contribute to the increased mortality risk of CWP.

2 | METHODS

2.1 | Study data

This study pooled data from 2011 to 2014 from the 5% Medicare Claims Limited Data Set (LDS)[21] across 48 contiguous United States. The data represent 5% of the individuals enrolled in Medicare Fee-For-Service, drawn randomly from the 50 million covered by Medicare in the United States. Data from the Medicare Claims LDS are presented as multiple linkable files. The LDS denominator file contains demographic information including age, sex, race, state and social security administration county codes (SSA codes) of residence, and date of death. The primary source of death information is from Social Security Administration and Railroad Retirement Board.[22] For this study, we selected variables from the denominator file, the Inpatient Claims File, the Outpatient Claims File, and

Carrier Files. We converted SSA codes to FIPS codes using publicly available crosswalk file.[23]

2.2 | Individual-level data

The analysis considered only the individuals whose claims were submitted for diagnostic codes ICD-9-CM 500-505, where ICD-9-CM 500 = CWP, 501 = Asbestosis, 502 = Pneumoconiosis due to other silica or silicates, 503 = Pneumoconiosis due to other inorganic dust, 504 = Pneumonopathy due to inhalation of other dust, and 505 = Pneumoconiosis, unspecified, between January 1, 2011, and December 31, 2014. We derived our primary binary outcome variable from the 5% Medicare Claims data (1 = death, 0 = alive). The individual-level independent variables included age in years, gender, race (White or nonWhite), type of pneumoconiosis (ICD-9-CM 500 CWP vs. ICD-9-CM 501–505, referred to hereafter as other-Pneumoconiosis),[24] and the number of comorbid conditions. The 5% Medicare data contain ICD-9 codes for up to 25 comorbid conditions including COPD, Chronic Bronchitis, Pneumonia, Hypertension, and so on. For each contact with a healthcare provider (such as clinic visits, hospitalizations) up to 25 ICD-9 diagnosis codes could have been filled. Any ICD-9 code other than 500–505 was considered as comorbidity.

2.3 | County-level data

Our county-level data included a binary variable indicating the patient's county residence as rural or urban and the county-level poverty rate. Rurality was assessed using Rural-Urban Commuting Area (RUCA) codes based on the 2010 census data.[25] Micropolitan low commuting, core small towns, small towns with high and low commuting, and areas with the primary flow to tracts outside of urban areas or clusters were designated as "rural" counties. Urban counties include all metropolitan areas and high commuting micropolitan. Poverty rates were retrieved from the County Health Rankings Website.[26] Data on active and abandoned mines were obtained from the Mine Safety and Health Administration.[27] Since rural areas with high poverty rates may be deprived of adequate healthcare resources and screenings needed for CWP and Other-Pneumoconioses, we assessed its impact on death risks. Also, the risk of CWP increases with working in mines, therefore we considered the proximity of active and abandoned mines as a potential confounder.

2.4 | Statistical analyses

First, we summarized our data first using descriptive statistical techniques, such as frequencies, medians, interquartile ranges, χ^2 tests, and Mann–Whitney tests. Then, we applied adjusted spatial binary regressions to assess the effects of CWP on mortality. The quintessential form of our binary logistic regression considering death/survival as an outcome is:

$$\log\{\pi_{ij}/(1 - \pi_{ij})\} = \mu + Z_j\theta + X_i\beta + v_j + \varepsilon_{ij}, \quad i = 1, ..., n_j, \ j = 1, ..., K. \quad (1)$$

In Equation (1), π_{ij} represents the risk of death from pneumoconiosis for the ith person residing in the jth county, which is explained by a set of individual and county-level characteristics X_i, and Z_j, county-specific random effects v_j, and individual random effects ε_{ij}. We imposed zero mean identical and independent Gaussian distribution with variance σ^2 on ε_{ij}. We considered three different models. In the first two regression models, the county-specific random effects were assumed zero mean identically and independently distributed Gaussian distribution with variance τ^2. In the third model, spatial random effects were characterized by 50 latent spatial factors defined on the continental United States These spatial-latent factors were selected using Clara Algorithm (Ruppert et al., 2003)[28]. The spatial covariance on them was characterized by bivariate basis functions defined on the county centroids. All models were fitted using INLA (Integrated Nested Laplace Approximation) in R Studio/R version 4.0.2.

3 | RESULTS

During 2011–2014, there were 2568 deaths out of 8531 pneumoconiosis cases in the sample. The counts and percentages of different types of Pneumoconiosis were observed in the data as: CWP (ICD-9-CM500) = 1632 (19.1%), Asbestosis (ICD-9-CM501) = 5932 (69.53%), Pneumoconiosis due to other silica or silicates (ICD-9-CM502) = 321 (3.76%), Pneumoconiosis due to other inorganic dust (ICD-9-CM503) = 192 (2.25%), Pneumonopathy due to inhalation of other dust (ICD-9-CM504) = 81 (0.9%), and Pneumoconiosis, unspecified (ICD-9-CM505) = 413 (4.84%). The median age of the sample was 76 years, with an IQR of 13 years. The median number of comorbid conditions among these patients was 4 with an IQR of 10. About 19% of the sample had CWP, 86.7% were male, 89.9% were white, and 28.3% lived in rural counties. There were 620 active coal mines in the United States in 2014, and about 14.15% of our sample lived in a county with at least one active coal mine. The median poverty rate of the counties for this sample was 14.9%, with an IQR of 4.2% (Table 1).

CWP substantially elevated the odds of death among Medicare beneficiaries (Table 2). Under Model 1, adjusted for age, Medicare beneficiaries had 18% elevated odds of death due to CWP (OR: 1.18, 95% Credible Interval (CrI): 1.04, 1.34). The odds ratios increased to 1.24 (95% CrI: 1.07, 1.45) and 1.25 (95% CrI: 1.06, 1.46), under Models 2 and 3. Individuals with pneumoconiosis living in rural counties had 14% excess mortality (Model 1, OR: 1.14, 95% CrI: 1.03, 1.27). However, 95% credible intervals calculated based on Models 2 and 3 for rurality included 1. The number of comorbid conditions elevated the death risk from pneumoconiosis across all three models with odds ratios of 1.09 (95% CrI: 1.08, 1.10), 1.09 (95% CrI: 1.09, 1.10), and 1.10 (95% CrI: 1.09, 1.11), respectively. Figure 1 displays the major comorbid conditions noted in the study population and those who died in the sample from CWP and

Variable	Frequency (%) (n = 8531)	Alive (%) (n = 5963)	Dead (%) n = 2568	p-value
CWP				
Yes	1632 (19.1)	1161 (19.5)	471 (18.3)	0.224
No	6899 (80.9)	4802 (80.5)	2097 (81.7)	
Gender				
Males	7398 (86.7)	5116 (85.8)	2282 (88.9)	<0.001
Females	1133 (13.3)	847 (14.2)	286 (11.1)	
Race				
Whites	7670 (89.9)	5331 (89.4)	2339 (91.1)	0.018
Non-Whites	861 (10.1)	632 (10.6)	229 (8.9)	
Region/Location				
Rural	2416 (28.3)	1697 (28.5)	719 (28.0)	0.665
Non-rural	6115 (71.7)	4266 (71.5)	1849 (72.0)	
Presence of mines				
Active mines	1207 (14.15)	850	357	0.043
Abondoned Only	1247 (14.62)	907	340	
No	6077 (71.23)	4206	1871	
Median co-morbid conditions (IQR)[a]	4.0 (10)	3.0 (7.0)	10.0 (14.0)	<0.001
Median poverty rate (%) (IQR)[a]	14.9 (4.2)	15.0 (7.0)	14.7 (7.1)	0.045

TABLE 1 Descriptive characteristics of medicare beneficiaries with a pneumoconiosis diagnosis, 2011–2014

[a]Median, interquartile range (IQR), and Mann–Whitney tests performed. χ^2 tests were used for the categorical variables.

TABLE 2 Bayesian logistic regression with spatial random effects regression analysis of county-level risk factors of mortality among Medicare beneficiaries, 2011–2014

Variable	Model 1 (95% CrI)	Model 2 (95% CrI)	Model 3 (95% CrI)
CWP			
Yes	1.18 (1.04–1.34)	1.24 (1.07–1.45)	1.25 (1.06–1.46)
No	Ref	Ref	Ref
Gender			
Males	0.78 (0.67–0.91)	1.01 (0.87–1.19)	1.02 (0.87–1.20)
Females	Ref	Ref	Ref
Race			
Whites	1.06 (0.90–1.25)	0.98 (0.82–1.17)	0.98 (0.82–1.18)
Non-Whites	Ref	Ref	Ref
Region/Location			
Rural	1.14 (1.03–1.27)	1.11 (0.98–1.26)	1.07 (0.93–1.22)
Non-rural	Ref	Ref	Ref
Presence of mines			
Abandoned only	0.89 (0.75–1.06)	1.01 (0.81–1.24)	0.87 (0.68–1.11)
No mines	1.06 (0.93–1.21)	1.19 (0.99–1.43)	1.08 (0.86–1.37)
Active mines	Ref	Ref	Ref
Number of co-morbid conditions	1.09 (1.08–1.10)	1.09 (1.09–1.10)	1.10 (1.09–1.10)
Poverty rate (%)	1.01 (1.00–1.02)	1.00 (0.99–1.01)	1.01 (0.99– 1.02)

Note: Model 1: This is a marginal model where we included one explanatory variable at a time. However, all models were adjusted for age. Model 2: We included all explanatory variables and assessed county effects using zero-mean Gaussian distribution. Model 3: In this model, we included all explanatory variables, and assessed county effects using spatial factors and bivariate basis functions on county centroids.
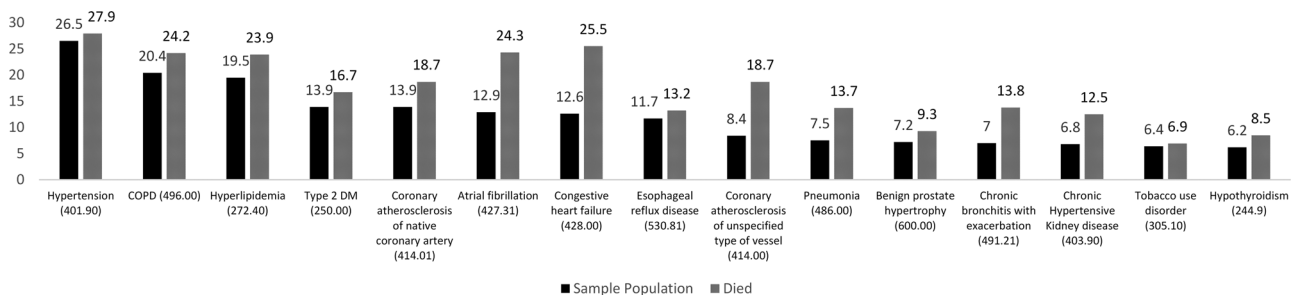

FIGURE 1 The distribution of comorbid conditions among the study population and those who died. The numbers above each bar represent percentages

other-Pneumoconioses. We noted that hypertension, COPD, atrial fibrillation, and congestive heart failure were the major four comorbid conditions among those who died.

4 | DISCUSSION

In this study, CWP was associated with 25% excess odds for death among Medicare beneficiaries compared to other pneumoconioses. Among the Federal Black Lung Benefits Program beneficiaries enrolled in Medicare between 1999 and 2016, Kurth et al.[29] found that 18.2% of the cases the cause of death was coal workers' pneumoconiosis, consistent with our findings of 18.3% based on 5% limited Medicare claims data set. In our study population, Medicare beneficiaries had an average age of 70 years, and most had multiple comorbidities. The mortality risk was higher in counties with high mining activity in the states of Kentucky, Pennsylvania, Virginia, and West Virginia. Several studies have reported an elevated risk of mortality among miners. Using the National Health Interview Survey (NHIS) Mortality Linked data, we reported a 26% elevated standardized mortality ratio among 18–64 years old who worked in the mining

industry[30] are compared to the general population, consistent with the current findings Mazurek et al.[15] reported that during the years 1996–2016, the mean ratio of years of potential life lost to life expectancy among decedents with CWP increased from 8.1 to 12.6. Additionally, of the 740 deaths due to CWP, 76% occurred among workers employed in the coal mining industry and 77% of deaths due to CWP occurred in Pennsylvania, West Virginia, Virginia, and Kentucky.[15] Using the National Health Interview Survey (NHIS) Mortality Linked data, we reported a 26% elevated standardized mortality ratio among 18–64-year-olds who worked in the mining industry.[30] With the resurgence of progressive massive fibrosis,[17] a severe form of CWP, mortality rates may rise, undermining decades of public health progress on preventing CWP. It is worth noting that exposure to crystalline silica is prevalent among coal miners.[31] Recent studies in the United States,[3] China,[32] and Australia [33] highlighted the coexistence of silicosis and CWP among coal miners, underscoring the need for continuous surveillance of respirable silica dust exposure levels among coal miners.

Using the Medicare data, we reported that, the presence of comorbidities increased death risks among patients with pneumoconiosis by 10%. The top three comorbid conditions in our sample were chronic pulmonary diseases, hypertension, and heart diseases. According to the study by Altınsoy et al.[27] about 15% of nonsmoking patients with CWP have COPD, and about 2/3rd of patients with Primary Myelofibrosis (PMF) have significantly impaired lungs.[34] Several cohort studies reported the elevated prevalence of lung cancer and chronic cardiopulmonary obstructive diseases among coal miners.[35] In earlier studies, based on the NHIS data, we found significantly increased odds of chronic diseases including hypertension, heart disease, and diabetes among ex-miners.[36] The top cause-specific standardized mortality ratios among those working in the mining industry were heart diseases, followed by unintentional injuries and cancer.[30]

Despite the richness of 5% Medicare data, several shortcomings are notable. Since information on occupation is unavailable in Medicare claims data, we were unable to precisely identify how many of them get the disease from working in coal mines. At an early stage, pneumoconiosis is asymptomatic and often undetectable, and severe symptoms develop over a long period. With only 4 years of data, we cannot account for the length of exposure and address the longitudinal progression of the disease. Additionally, beneficiaries' county residences were based on the Medicare enrollment information and this residence may not be the same as beneficiaries' residence while employed.

Several counties reported a small number of deaths, which can increase uncertainties in estimates. CWP is primarily an occupational lung disease, and patients have to undergo rigorous medical screening for diagnosis. Therefore, misclassification of the outcome is highly unlikely, but the coding errors cannot be eliminated.

In conclusion, we found that Medicare beneficiaries with CWP carried a substantial burden of comorbidities and had significantly elevated odds of mortality due to CWP compared to Medicare beneficiaries with other types of pneumoconiosis. Ex-miners continue to face excess disease burden on mortality risk despite cessation of exposure. Healthcare professionals should make concerted efforts to monitor patients with CWP to prevent premature mortality.

Premature mortality can be prevented by early detection, ensuring access to healthcare resources needed to treat CWP and these types of lung diseases, creating awareness of symptoms of CWP and complications when CWP is associated with comorbidities and other respiratory diseases, such as Covid-19.[15] Additionally improving ventilation systems and new technologies for dust suppression devices would be helpful.[37]

CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

DISCLOSURE BY AJIM EDITOR OF RECORD

John Meyer declares that he has no conflict of interest in the review and publication decision regarding this article.

INSTITUTION AND ETHICS APPROVAL AND INFORMED CONSENT

The University of North Carolina at Charlotte Institutional Review Board exempted the study.

AUTHOR CONTRIBUTIONS

Ahmed A. Arif acquired the data, Rajib Paul and Oluwaseun Adeyemi analyzed the data, Rajib Paul and Oluwaseun Adeyemi drafted the first version of the manuscript, Rajib Paul and Ahmed A. Arif contributed to the conception and design of this study. All authors contributed to the writing of the manuscript. All authors critically revised the manuscript and approved the manuscript for submission.

DATA AVAILABILITY STATEMENT

The data are not publicly available due to data sharing agreement, privacy, and/or ethical restrictions. However, the authors will be happy to share the computer codes upon request.

ORCID

Rajib Paul http://orcid.org/0000-0002-5120-7525
Ahmed A. Arif http://orcid.org/0000-0002-0237-9937

REFERENCES

1. Dang G, Barros N, Higgins S, Langley R, Lipton D. Descriptive review of asbestosis and silicosis hospitalization trends in North Carolina, 2002–2011. *N C Med J*. 2013;74(5):368-375.
2. Heppleston AG. Prevalence and pathogenesis of pneumoconiosis in coal workers. *Environ Health Perspect*. 1988;78:159-170. doi:10.1289/ehp.8878159

3. Cohen RA. Resurgent coal mine dust lung disease: wave of the future or a relic of the past? Editorial. *Occup Environ Med*. 2016;11(11):715-716. doi:10.1136/oemed-2016-103737. 73.

4. Laney AS, Attfield MD. Coal workers' pneumoconiosis and progressive massive fibrosis are increasingly more prevalent among workers in small underground coal mines in the United States. *Occup Environ Med*. 2010;67(6):428-431. doi:10.1136/oem.2009.050757

5. Attfield M, Petsonk E. Advanced pneumoconiosis among working underground coal miners—Eastern Kentucky and Southwestern Virginia, 2006. *JAMA*. 2007;298(7):734-736. doi:10.1001/jama.298.7.734

6. Centers for Disease Control and Prevention. Advanced cases of coal workers' pneumoconiosis—two counties, Virginia, 2006. *JAMA*. 2006;296(17):2085-2086. doi:10.1001/jama.296.17.2085

7. National Institute for Occupational Safety and Health. *Prevalence of Black Lung Continues to Increase among U.S. Coal Miners*; 2018;

8. Blackley DJ, Halldin CN, Laney AS. Continued increase in prevalence of coal workers' pneumoconiosis in the United States, 1970-2017. *Am J Public Health*. 2018;108(9):1220-1222. doi:10.2105/AJPH.2018.304517

9. Arif AA, Paul R, Delmelle E, Owusu C, Adeyemi O. Estimating the prevalence and spatial clusters of coal workers' pneumoconiosis cases using medicare claims data, 2011-2014. *Am J Ind Med*. 2020;63:478-483. doi:10.1002/ajim.23104

10. Tomaskova H, Splichalova A, Slachtova H, et al. Mortality in miners with coal-workers' pneumoconiosis in the Czech Republic in the Period 1992-2013. Research Support, Non-U.S. Gov't. *Int J Environ Res Public Health*. 2017;14(3):07. doi:10.3390/ijerph14030269

11. Meijers JM, Swaen GM, Slangen JJ. Mortality of Dutch coal miners in relation to pneumoconiosis, chronic obstructive pulmonary disease, and lung function. *Occup Environ Med*. 1997;54(10):708-713.

12. Meijers JM, Swaen GM, Slangen JJ, van Vliet K, Sturmans F. Long-term mortality in miners with coal workers' pneumoconiosis in The Netherlands: a pilot study. *Am J Ind Med*. 1991;19(1):43-50. doi:10.1002/ajim.4700190106

13. U.S. Energy Information Administration. *Country Analysis Executive Summary: China*; 2020. https://www.eia.gov/international/content/analysis/countries_long/China/china.pdf

14. Han L, Gao Q, Yang J, et al. Survival analysis of coal workers' pneumoconiosis (CWP) patients in a state-owned mine in the East of China from 1963 to 2014. *Int J Environ Res Public Health*. 2017;14(5):06. doi:10.3390/ijerph14050489

15. Mazurek JM, Wood J, Blackley DJ, Weissman DN. Coal workers' pneumoconiosis-attributable years of potential life lost to life expectancy and potential life lost before age 65 years—United States, 1999-2016. *Morb Mortal Wkly Rep*. 2018;67(30):819-824. doi:10.15585/mmwr.mm6730a3

16. Blackley DJ, Crum J, Halldin C, Storey E, Laney A. Resurgence of progressive massive fibrosis in coal miners—Eastern Kentucky, 2016. *Morb Mortal Wkly Rep*. 2016;65:1385-1389.

17. Blackley DJ, Halldin CN, Laney AS. Resurgence of a debilitating and entirely preventable respiratory disease among working coal miners. *Letter Am J Respir Crit Care Med*. 2014;190(6):708-709. doi:10.1164/rccm.201407-1286LE

18. Perret JL, Plush B, Lachapelle P, et al. Coal mine dust lung disease in the modern era. *Rev Respirol*. 2017;22(4):662-670. doi:10.1111/resp.13034

19. Zhang X, Holt JB, Lu H, et al. Multilevel regression and post-stratification for small-area estimation of population health outcomes: a case study of chronic obstructive pulmonary disease prevalence using the behavioral risk factor surveillance system. *Am J Epidemiol*. 2014;179(8):1025-1033. doi:10.1093/aje/kwu018

20. Eastwood JG, Jalaludin BB, Kemp LA, Phung HN, Barnett BEW. Immigrant maternal depression and social networks. A multilevel Bayesian spatial logistic regression in South Western Sydney, Australia. *Spatial Spatio Temp Epidemiol*. 2013;6:49-58. doi:10.1016/j.sste.2013.04.003

21. Center for Medicare and Medicaid Services. *Public Use File*. Medicare Geographic Variation; 2019: 2020(02/26/2020).

22. Jarosek S *Death Information in the Research Identifiable Medicare Data*. Research Data Assistance Center. https://resdac.org/articles/death-information-research-identifiable-medicare-data

23. National Bureau of Economic Research. *SSA to Federal Information Processing Series (FIPS) Core-Based Statistical Area (CBSA) and Metropolitan and Micropolitan Statistical Area (MSA) County Crosswalk*. https://www.nber.org/research/data/ssa-federal-information-processing-series-fips-core-based-statistical-area-cbsa-and-metropolitan-and

24. DeLight N, Sachs H *Pneumoconiosis*. *StatPearls*. StatPearls Publishing; 2021. https://www.ncbi.nlm.nih.gov/books/NBK555902/

25. Economic Research Services. *Rural-Urban Commuting Area Codes*. United States Department of Agriculture. https://www.ers.usda.gov/data-products/rural-urban-commuting-area-codes/

26. University of Wisconsin Population Health Institute*County Health Rankings State Reports*. *County Health Ranking and Road Maps*. University of Wisconsin Population Health Institute; 2020.

27. National Institute for Occupational Safety and Health. *MSHA Data File Downloads*. Centers for Disease Control and Prevention. https://www.cdc.gov/niosh/mining/data/default.html

28. Ruppert D, Wand MP, Carroll RJ. *Semiparametric Regression*.: Cambridge University Press; 2003:

29. Kurth L, Halldin C, Laney AS, Blackley DJ. Causes of death among federal Black lung benefits program beneficiaries enrolled in medicare, 1999-2016. *Am J Ind Med*. 2020;63(11):973-979. doi:10.1002/ajim.23176

30. Arif AA, Adeyemi O. Mortality among workers employed in the mining industry in the United States: A 29-year analysis of the National Health Interview Survey-Linked Mortality File, 1986-2014. *Am J Ind Med*. 202063(10):851–858. doi:10.1002/ajim.23160

31. Castranova V, Vallyathan V. Silicosis and coal workers' pneumoconiosis. *Environ Health Perspect Suppl*. 2000;108:675-684.

32. Yang LT, Liu X, Wu GH, Chen LF. Association between tumor necrosis factor-α −308 Gauss/A polymorphism and risk of silicosis and coal workers pneumoconiosis in Chinese population. *Inhal Toxicol*. 2018;30(6):213-217. doi:10.1080/08958378.2018.1494766

33. Penrose B. Re-emergence of silicosis and coal workers pneumoconiosis in Australia. *Labour Hist*. 2020;119:65-92. doi:10.3828/jlh.2020.19

34. Altınsoy B, Öz İİ, Erboy F, Tor M, Atalay F. Emphysema and airflow obstruction in non-smoking coal miners with pneumoconiosis. *Med Sci Monit*. 2016;22:4887-4893. doi:10.12659/msm.901820

35. Go LH, Krefft SD, Cohen RA, Rose CS. Lung disease and coal mining: what pulmonologists need to know. *Rev Curr Opin Pulm Med*. 2016;22(2):170-178. doi:10.1097/MCP.0000000000000251

36. Arif A, Adeyemi O. The prevalence of chronic diseases among current and ex-miners in the United States. *J. Occup. Environ. Med*, 2020.62(3):227–231.

37. Mazurek JM, Laney AS, Wood JM. National Institute for Occupational Safety and Health. Coal workers' pneumoconiosis-related years of potential life lost before age 65 Years—United States, 1968-2006. *JAMA*. 2010;303(16):1591-1593. https://jamanetwork.com/journals/jama/fullarticle/185767