Risk Analysis, Vol. 38, No. 9, 2018 DOI: 10.1111/risa.13000

Interstitial Lung Diseases in the U.S. Mining Industry: Using MSHA Data to Examine Trends and the Prevention Effects of Compliance with Health Regulations, 1996–2015

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Given the recent increase in dust-induced lung disease among U.S. coal miners and the respiratory hazards encountered across the U.S. mining industry, it is important to enhance an understanding of lung disease trends and the organizational contexts that precede these events. In addition to exploring overall trends reported to the Mine Safety and Health Administration (MSHA), the current study uses MSHA's enforcement database to examine whether or not compliance with health regulations resulted in fewer mine-level counts of these diseases over time. The findings suggest that interstitial lung diseases were more prevalent in coal mines compared to other mining commodities, in Appalachian coal mines compared to the rest of the United States, and in underground compared to surface coal mines. Mines that followed a relevant subset of MSHA's health regulations were less likely to report a lung disease over time. The findings are discussed from a lung disease prevention strategy perspective.

KEY WORDS: Interstitial lung diseases; U.S. mining industry

1. INTRODUCTION

Of the estimated 2.3 million worldwide occupationally related fatalities in 2012, 2 million were attributable to occupationally related diseases—approximately 8% of which were respiratory diseases (Takala, Hamalainen, & Saarela, 2014). In 2012, an estimated 95,808 U.S. workers died from work-related diseases (Takala et al., 2014). In addition to the familial, social, and opportunity costs, the financial cost of each of these fatalities has been estimated at $330,000, resulting in total economic burden of $31.6 billion (Leigh, 2011). Given the enormous economic, organizational, and social burden of these occupationally related fatalities, purposeful and dedicated efforts to minimize their risk of occurrence are warranted.

Within the United States, occupationally related fatalities due to accidents/injuries have steadily decreased in nearly every industry, including the mining industry (MSHA, 2015; OSHA, 2016). However, within the last decade, the burden of debilitating lung disease in the coal mining industry has sharply increased (Arnold, 2016; Blackley, Crum, Halldin, Storey, & Laney, 2016; Blackley, Halldin, & Laney, 2014; Blackley, Halldin, Cummings, & Laney, 2016b). Lung diseases associated with coal

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Disclaimer: The findings and conclusions in this report are those of the author(s) and do not necessarily represent the official position of the National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention.

 0272-4332/18/0100-1962$22.00/1

mining employment include classic coal workers' pneumoconiosis (CWP), silicosis, mixed dust pneumoconiosis, chronic obstructive pulmonary disease (COPD), dust-related diffuse fibrosis, and the most severe form, progressive massive fibrosis (PMF).

New cases of lung disease arising from employment in the coal mining industry have been observed in younger miners, across mining commodities, and within surface as well as underground mines (Antao, Petsonk, & Sokolow, 2005; Halldin, Laney, Wolfe, & Petsonk, 2012; Halldin, Reed, & Joy, 2015). As described in the literature (Blackley et al., 2014; Laney & Weissman, 2012; Mazurek, Laney, & Wood, 2009; Wade, Petsonk, Young, & Mogri, 2011), these increases have been observed by a number of independent data sources, including: the federally mandated National Institute for Occupational Safety and Health (NIOSH) administered Coal Workers' Health Surveillance Program (CWHSP); mortality data from deceased miners; federal black lung compensation and state compensation disability claims; and in national transplant registry data.

Compliance with Mine Safety and Health Administration's (MSHA) requirements is one strategy that mines utilize to prevent lung disease. Many mines also establish health and safety efforts that exceed these minimum obligations. With limited resources available, health and safety leaders must determine how much to invest in each activity. There is an absence of research to help prioritize and provide guidance for these investment activities. Given the recent issues with dust-induced lung diseases in coal mines and the potential for hazardous exposures to cause lung diseases in other parts of the mining industry, research that can help align resource allocation decisions with activities that are known to have a positive return on investment is needed.

Robust studies that provide empirical evidence regarding the types of organizational contexts that precede lung diseases in the mining industry and an enhanced understanding of the lung disease trends are a critical next step. Given that MSHA requires mining establishments to report injuries and illnesses, the database that contains this information can be a rich source of information to better understand lung disease trends in the U.S. mining industry. Trends derived from MSHA data may be additionally informative given the prospect of linking occurrences of lung diseases within a mine to patterns of historical compliance with MSHA rules designed to prevent lung diseases. Doing so allows us to examine whether or not dedicating resources to achieve greater levels of compliance or to exceed the minimum set requirements can decrease the probability of lung disease occurrences within a mine over time.

The current study was designed to address this gap by using the publicly available MSHA injury and illness and the enforcement databases: (1) to derive an understanding of the reported trends of occupational lung diseases in the mining industry; and (2) to examine whether or not mines that consistently complied with a relevant subset of MSHA's health standards were associated with lower counts of lung diseases over time. In doing so, this study contributes to the empirically grounded body of evidence designed to strengthen our understanding of lung disease trends and guide evidence-based prevention of mining-related occupational lung disease.

2. METHODS

2.1. Data

Each of the databases used in the current study (i.e., the MSHA enforcement database, the MSHA injury and illness database, and the MSHA address and employment database) was obtained from the U.S. Department of Labor's enforcement data portal (U.S. Department of Labor, 2017). Given the long latency period for lung diseases—often times requiring 10 or more years of exposure before radiographic abnormalities become visible (Blackley et al., 2016; Cocco, 2003; Hurley, Burns, Copland, Dodgson, & Jacobsen, 1982; Leung, Yu, & Chen, 2012; Steenland, Mannetje, & Boffetta, 2001)—and the desire to have compliance information that preceded diagnosis by at least 10 years, each database was downloaded for the years 1996–2015.

Instances of the interstitial lung diseases (pneumoconiosis, silicosis, and asbestosis) associated with mines were derived from the MSHA injury and illness database. As specified in the Code of Federal Regulations (CFR), 30 CFR Part 50 requires all accidents, injuries, and illnesses that occur at a mining operation be documented on Form 7000–1 and mailed to MSHA within 10 working days after an accident or occupational injury occurs or illness is diagnosed. The MSHA injury and illness database is derived from Form 7000–1 and includes a record for each injury and illness that a miner experienced by year, corresponding to each mine in which the individual worked. Within the database, each event is associated with numerous variables and each variable has numerous codes that are used to classify the event. The "Nature of Injury/Illness" variable was used in the current study to determine the number of lung diseases miners experienced within each mine. This variable codes the injury/illness directly as a medically diagnosed case of pneumoconiosis, silicosis, or asbestosis. Within this database, each recordable event for pneumoconiosis, silicosis, and asbestosis between 2006 and 2015 was counted through a unique variable. An additional variable was created that counted the total number of reported lung diseases—with a count imposed for each case of pneumoconiosis, silicosis, and asbestosis cases—during the same time period.

MSHA's enforcement database, also publicly available, includes a record for each instance in which an MSHA inspector observed and documented an occurrence of noncompliance. These inspections take place four times annually for each operating underground mine and two times annually for each operating surface mine. Within this database a variable is included that corresponds to the geographically delineated MSHA district responsible for the inspection.

Table I. MSHA Standards Used in Analysis

Management Practice Regulations to Prevent Lung Diseases in the Mining Industry	Engineering Control Regulations to Prevent Lung Diseases in the Mining Industry
56.5002, 56.5005, 57.5002, 57.5005, 57.5037, 57.5040, 57.5044, 57.5045, 57.5046, 57.5047, 57.5060, 57.5071, 58.610, 70.201, 70.202, 70.203, 70.204, 70.205, 70.206, 70.207, 70.208, 70.209, 70.210, 70.211, 70.212, 70.1900, 71.201, 71.202, 71.203, 71.204, 71.205, 71.206, 71.207, 71.208, 71.209, 71.300, 71.301, 72.510, 72.610, 72.700, 72.701, 72.710, 90.201, 90.202, 90.203, 90.204, 90.205, 90.206, 90.207, 90.208, 90.209	56.5001, 57.5001, 57.5038, 57.5039, 70.100, 70.101, 71.100, 71.101, 71.700, 71.702, 72.500, 72.501, 72.502, 72.620, 72.630, 90.100, 90.101

2.2. Data Coding and Research Design

The MSHA requirements outlined in the CFR include numerous rules designed to prevent lung diseases. These rules encompass both the engineering controls necessary to eliminate or reduce airborne contamination to healthy levels and the management practices needed to monitor the work environment, communicate airborne hazards, and provide personal respiratory protection where appropriate.

In terms of engineering controls, MSHA includes numerous standards that direct underground and surface coal mines to maintain a working environment with noted airborne contaminants below a certain level (e.g., dusts and fumes). MSHA also requires coal, metal, and nonmetal mine operators to ensure that workers are not exposed to inhalation hazards that exceed the American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Values (TLVs).

In terms of management practices, MSHA includes numerous standards that require activities necessary for the worksite to accurately understand and communicate the levels of airborne contaminants and to provide NIOSH-approved personal respiratory protection where appropriate. For example, MSHA requires that a dust control plan be in place to control airborne contaminants that includes conducting and communicating air quality sampling at certain intervals, by approved devices, and by qualified persons. Also, for example, MSHA requires that an adequate supply of NIOSH-approved respiratory protective equipment be made available to all coal and metal/nonmetal miners and be used during short periods of time (for coal) and reasonable periods of time (for metal/nonmetal) where concentrations of gas, dusts, fumes, or mists exceed permissible levels.

Within the MSHA standards we found 17 total instances in which a standard mandates that mines continuously maintain airborne contaminants below a specified level and 51 instances in which a standard mandates that mines accurately assess the airborne respiratory hazards, communicate the results of the assessments, and provide personal respiratory protection when appropriate. These rules span coal, metal, nonmetal, stone, sand, and gravel mining commodities. The standard numbers delineated by the categories used in this study are shown in Table I. A full version of the MSHA standards, including the rules used within the current study, can be found through MSHA's website. Within the enforcement database for the years 1996–2005, each instance in which a mine failed to comply with one of the standards referenced in Table I was coded with a count according to the appropriate category.

After coding with counts, each of the databases was aggregated to the level of the mine by year. Each case within the distinct databases that corresponded to the same mine was then linked together by mine

ID. Through the mine status and hours worked variables within the MSHA address and employment database, zeros were imputed for instances where a mine was active but experienced no reportable cases within the injury and illness database and in which no MSHA inspector observed instances of noncompliance were found within the enforcement database. This step ensured the available population of mines was not limited to those that experienced an injury, illness, and/or those included in the MSHA enforcement database for a given year.

Control variables were chosen based on factors described in the literature as most likely to be related to an individual miner's diagnosis of a lung disease. When estimating the prevalence of pneumoconiosis among miners of different regions, a previous study controlled for total mining tenure given that the development and severity of lung disease is related to both duration and concentration of exposure (Halldin et al., 2012). Another study found evidence to suggest that occurrences of lung disease can differ by age groups (Mazurek & Attfield, 2008). Thus, both the average tenure and age of the miners reported within the injuries and illnesses database for each mine from 2006 to 2015 were computed and used as control variables.

The resulting database included data for a 20-year time period (1996–2015) with a mean time lag of 10 years and the possibility of ± 5 years between compliance information and the number of lung diseases for specific mines. This design accounts for epidemiologic evidence that suggests a 10-year time lag between repeated exposure to hazardous concentrations of airborne contaminants and disease diagnosis—with the possibility of accelerated cases (diagnosis approximately five years) and others with >10-year time lag from exposure to diagnosis (Blackley et al., 2016; Cocco, 2003; Hurley et al. 1982; Leung et al., 2012; Steenland et al., 2001). The structure of the database allowed us to examine whether or not mines that did a better job of complying with relevant health rules during the 1996–2005 time period experienced fewer lung diseases 2006–2015.

3. RESULTS

3.1. Descriptive Statistics

Approximately 30,000 total mines were active at some point within the 1996–2015 time span. The total number of mines with years of activity within each of the two delineated time periods (1996–2005 and 2006–2016) was 12,999. Of the 12,999 mines, 8,165 mines included information pertaining to all of the variables of interest (MSHA district, mine type, commodity, and the identified statistical controls).

Given the proportion of total reported lung diseases that were cases of pneumoconiosis, Table II shows the distribution of total lung diseases and cases of pneumoconiosis from 2006 to 2015 in the final sample by commodity (coal vs. non-coal) and MSHA district. The area covered by each MSHA district (column 4) was used to derive the relevant U.S. regions shown in column 5. As depicted in Table II, the large majority of total lung diseases ($n = 730$) were reported from coal mines ($n = 662$), all of which were cases of pneumoconiosis. The remaining lung diseases (below the dashed line) were reported from non-coal commodities ($n = 68$; pneumoconiosis = 7, silicosis = 55, asbestosis = 6).[4]

Within coal mines, the majority of lung diseases originated in the Appalachian region of the United States ($n = 640$) compared to the total of the western, southern, and North Central regions ($n = 22$). In addition, underground coal mines had more cases ($n = 558$) when compared to surface coal mines ($n = 104$).

Given this distribution of lung diseases by mining commodity, U.S. region, and type, we chose to examine: (1) the effects of compliance on total lung diseases in all U.S. mines using mine commodity (coal vs. non-coal establishments) as a categorical predictor and potential statistical moderator; (2) the effects of compliance on pneumoconiosis in coal mines with U.S. region (Appalachian vs. the rest of United States) and type of coal mining (underground vs. surface) as categorical predictors and potential statistical moderators.

Within the total sample, the average, standard deviation (SD), and total number of lung diseases were: $M = 0.06$, $SD = 0.75$, total count = 730. Within the total sample, the average, standard deviation (SD), and total number of pneumoconiosis cases were: $M = 0.05$, $SD = 0.74$, total count = 669. The average mining experience within each

[4]Out of the seven pneumoconiosis cases reported from non-coal commodities three were reported from metal/nonmetal mines and four were reported from stone/sand/gravel mines. Of the 55 reported cases of silicosis, 35 were reported from metal/nonmetal mines and 20 were reported from stone/sand/gravel mines. Of the six asbestosis cases, five were reported from metal/nonmetal mines and one was reported from a stone/sand/gravel mine.

Table II. Distribution of Lung Diseases and Pneumoconiosis Cases from 2006 to 2015 in Coal and Non-Coal Mines by MSHA District and U.S. Region

Total Lung Disease Cases	Cases of Pneumoconiosis	MSHA District	Area Covered	U.S. Region	Commodity
1	1	District 1	Anthracite coal in PA	Appalachian	Coal
9	9	District 2	Bituminous and anthracite coal in PA	Appalachian	Coal
53	53	District 3	MD, OH, and northern WV	Appalachian	Coal
321	321	District 4	Southern WV	Appalachian	Coal
174	174	District 5	VA and eastern KY	Appalachian	Coal
23	23	District 6	Eastern KY	Appalachian	Coal
55	55	District 7	Central KY, NC, SC, and TN	Appalachian	Coal
5	5	District 8	IL, IN, IA, MI, MN, northern MO, and WI	North Central	Coal
12	12	District 9	AK, AZ, CO, MT, NM, ND, UT, WA, and WY	West	Coal
2	2	District 10	Western KY	Appalachian	Coal
5	5	District 11	AL, GA, FL, MS, PR, VI, LA, TX, AR, OK, KS, and southern MS	South	Coal
2	2	District 12	Southern WV	Appalachian	Coal
10	2	MNC	IL, IN, IA, MI, MN, WI	North Central	Non-Coal
9	3	MNE	CT, DE, DC, ME, MD, MA, NH, NY, NJ, OH, PA, RI, VT, WV, VA	North Eastern	Non-Coal
5	0	MRM	AZ, CO, KS, MO, NE, ND, SD, UT, WY, ID	Rock Mountain	Non-Coal
9	0	MSC	AR, LA, MO, NM, OK, TX, MS	South Central	Non-Coal
19	2	MSE	AL, FL, GA, KY, NC, PR, SC, TN, VI, MS	South Eastern	Non-Coal
16	0	MWE	AK, CA, HI, NV, OR, AZ, UT, WA, ID	Western	Non-Coal

Note: Total lung diseases includes reported cases of pneumoconiosis, silicosis, and asbestosis. MSHA districts 1 and 6 are former districts. MNC, MNE, MRM, MSC, MSE, and MWE are MSHA's metal/nonmetal designated districts corresponding to their regional location.

mine was 14.4 years ($SD = 10.0$). The average age of miners was 44.8 years ($SD = 10.3$). Average miner age and tenure were correlated within the total sample at 0.55, $p < 0.05$. The average number of inspector observed instances of noncompliance with a management practice standard was 0.22 ($SD = 1.4$) and the average number of inspector observed instances of noncompliance with an engineering control standard was 0.49 ($SD = 1.7$).

3.2. Selection of Statistical Models

The total number of lung diseases and cases of pneumoconiosis reported by mines (i.e., the dependent variables) were not normally distributed. Rather, they are counts of lung diseases that occurred within a mine between 2006 and 2015. Poisson, Negative Binomial (NB), Zero Inflated Poisson (ZIP), and Zero Inflated Negative Binomial (ZINB) models were compared using goodness-of-fit-statistics. The Negative Binomial models provided a significantly better fit than the Poisson models. Although the ZINB has slightly lower values in −2 log likelihood, the ZINB has slightly higher values of Akaike information criterion (AIC). Formal comparisons of AIC were made between the two lowest scoring models (NB and ZINB), suggested that the ZINB and NB models did not significantly differ in fit (Vuong test $p > 0.05$ for both outcomes). This nonsignificant difference, coupled with the lack of clear justification in support of a two-part ZINB process (Lord, Washington, & Ivan, 2005), points to the negative binomial model as the most appropriate.

Four distinct generalized linear models with negative binomial distribution and log link were executed to further quantify the overall trends of lung diseases and examine the influence of inspector observed instances of noncompliance (1996–2005) on counts of lung diseases (2006–2015). For the analysis in the total sample of mines (n = 8,165), the regression equation took the form of:

$$\begin{aligned} & Log\ \ (P\,[Total\ Lung\ Diseases_{i,2006-2015}]) \\ & = B_0\ +B_1(Average\ Age)_{i,2006-2015} \\ & \quad + B_2(Average\ Tenure)_{i,2006-2015} + B_3(Commodity)_i \\ & \quad + B_4(Number\ of\ management\ practice \\ & \qquad noncompliance\ instances)_{i,1996-2005} \end{aligned}$$

Within the coal mine subset (n = 1,634), the regression equation took the form of:

$$\begin{aligned} & Log\ \ (P[Pneumoconiosis_{i,2006-2015}]) \\ & = B_0\ +B_1(Average\ Age)_{i,2006-2015} \\ & \quad + B_2(Average\ Tenure)_{i,2006-2015} \\ & \quad + B_3(U.S.\ Region)_i +\ B_4(Mining\ Type)_i \\ & \quad + B_5(Number\ of\ management\ practice \\ & \qquad noncompliance\ instances)_{i,1996-2005} \end{aligned}$$

These models were repeated for the number of inspector observed instances of noncompliance with an MSHA requirement for engineering controls (1996–2005). The interpretation of the exponentiated regression coefficient (the Incident Risk Ratio—IRR) for B_4 in the total sample and B_5 in the coal subset is the increased/decreased probability for a mine to experience a lung disease 2006–2015 for each unit increase of observed noncompliance 1996–2005. The coefficients corresponding to the categorical predictors represent the relative risk in relation to the following: the coal subset in reference to the non-coal subset for the *Commodity* variable; the Appalachian region in relation to all other U.S. regions for the *U.S. Region* variable; and underground coal mines in relation to surface coal mines for the *Mining Type* variable. The results of the analysis within the total sample of mines and within the coal mine subset are shown in Table III and Table IV, respectively.

3.3. Results of Statistical Models

The base models (where control variables were entered as individual predictors) reported in Table III suggest that, of the two control variables, only average mining tenure was a significant predictor of total lung diseases ($B = 0.11$, t value $= 9.19$, $p < 0.001$). The exponentiated regression estimate in this case (0.11) is equal to the IRR reported in Table III (1.12), suggesting that the likelihood of a diagnosed lung disease in a mining establishment increased by 12% as the average tenure of miners within that establishment increased by 1 year.

Both models 1 and 2 in Table III show the same pattern of significance and relative effect size for the control variables and the dichotomous commodity variable included in the model. As in the base model, the average age of the mine worker was not significantly associated with total lung diseases in models 1 and 2. The total tenure, however, remained significant, suggesting that as a mine's average total mining experience of its miners increased by one year there was a 13% (IRR for Mining Tenure in Table III, models 1 and 2) increased probability of a mine worker to report a lung disease during the 2006–2015 time period.

There was also a significant difference in the probability of a miner reporting a lung disease between coal and non-coal mining commodities. The estimated mean number of lung diseases in a coal mine was 0.158 compared to 0.010 for non-coal mine commodities ($t = 3.79$, $p < 0.001$). This mean difference was associated with an approximate 16 (IRR for Commodity in Table III, model 1) to 17.8 (IRR for Commodity in Table III, model 2) higher probability for a coal mine to have a miner report a lung disease during the 2006–2015 time period compared to non-coal mine commodities. These IRRs were derived by exponentiating the regression coefficients estimated for the commodity categorical variables in each of the two models (B = 2.77 and B = 2.88, respectively), where the non-coal commodity was modeled as the reference group.

Table III also shows that for each unit increase in an inspector observed instance of noncompliance with management practice regulations, there was a 14% increase in the probability of that mine reporting a lung disease in future years. For each unit increase in an inspector observed instance of noncompliance with an engineering control regulation, there was a 22% increase in the probability of that mine reporting a lung disease in future years.

The models for pneumoconiosis in coal mines (Table IV) suggest that both average age and tenure were significant predictors in the base models (IRR = 1.08, p = 0.005 and IRR = 1.14, $p < 0.001$, respectively), but dropped from significance when adjusting for the other predictors in models 1 and 2. There was a significant mean difference between

Table III. Total Lung Diseases in Complete Sample Regression Results

	Estimate	Std. Error	*t* Value	*p* Value	Incident Risk Ratio (IRR)	IRR 95% CI Lower Bound	IRR 95% CI Upper Bound
				Base Model: Control variables			
Miner age	0.03	0.01	1.80	0.07	1.03	0.99	1.06
Mining tenure	0.11***	0.01	9.19	<0.001	1.12	1.09	1.14
				Model 1: Management practices			
Miner age	−0.04	0.03	−1.34	0.18	0.96	0.90	1.02
Mining tenure	0.13***	0.03	3.66	<0.001	1.13	1.06	1.21
Commodity	2.77***	0.31	9.05	<0.001	16.01	8.78	29.21
Management practices	0.13*	0.06	2.16	0.03	1.14	1.02	1.29
				Model 2: Engineering controls			
Miner age	−0.04	0.04	−0.96	0.34	0.97	0.90	1.04
Mining tenure	0.13***	0.04	3.32	<0.001	1.13	1.05	1.22
Commodity	2.88***	0.32	8.92	<0.001	17.80	9.45	33.50
Engineering controls	0.20***	0.06	3.22	<0.001	1.22	1.08	1.37

Note: $n = 8{,}165$. ***, $p < 0.001$; **, $p < 0.01$; *, $p < 0.05$. For commodity, coal is contrasted with all non-coal commodities with non-coal commodities as the reference group. The interaction terms between workplace practices and conditions from 1996–2005 and mining commodity were not significant.

Table IV. Pneumoconiosis in Coal Mines Regression Results

	Estimate	Std. Error	*t* Value	*p* Value	Incident Risk Ratio (IRR)	IRR 95% CI Lower Bound	IRR 95% CI Upper Bound
				Base Models: Control variables			
Miner age	0.08**	0.03	2.83	0.005	1.08	1.02	1.14
Mining tenure	0.13***	0.03	4.92	<.001	1.14	1.08	1.20
				Model 1: Management practices			
Miner age	0.05	0.04	1.15	0.25	1.05	0.99	1.14
Mining tenure	0.06	0.04	1.59	0.11	1.06	0.99	1.15
U.S. region	1.22***	0.42	−2.89	<.001	3.40	1.48	7.78
Mine type	2.08***	0.24	−8.69	<.001	8.00	5.00	12.80
Management practices	0.12**	0.04	2.86	0.004	1.12	1.04	1.16
				Model 2: Engineering controls			
Miner age	0.07	0.04	1.54	0.12	1.07	0.98	1.16
Mining tenure	0.07	0.04	1.68	0.09	1.07	0.99	1.15
U.S. region	1.00**	0.41	−2.44	0.01	2.73	1.22	6.12
Mine type	2.28***	0.24	−9.60	<.001	9.78	6.14	15.58
Engineering controls	0.10***	0.03	3.40	<.001	1.10	1.04	1.16

Note: $n = 1{,}634$. ***, $p < 0.001$; **, $p < 0.01$; *, $p < 0.05$. For U.S. region, the Appalachian region is contrasted with the rest of the United States with the rest of the United States as the reference group. For mine type, underground coal is contrasted with surface coal with surface coal mines as the reference group. The interaction terms between workplace practices and conditions from 1996 to 2005 and mining type and U.S. region were not significant.

mines located in the Appalachian region ($M = 0.332$) and mines located in other U.S. regions ($M = 0.98$, $t = 4.084$, $p < 0.001$). This difference was associated with an approximate 2.73 (IRR for U.S. region in Table IV, model 2) to 3.40 (IRR for U.S. region in Table IV, model 1) times higher probability for a coal mine located in the Appalachian region of the United States to report a case of pneumoconiosis during the 2006–2015 time period when compared to coal mines located in all other regions. There was also a significant difference in average reported cases of pneumoconiosis for underground coal mines ($M = 0.509$) and surface coal mines ($M = 0.064$, $t = 3.86$, $p < 0.001$). This difference was associated with an approximate 8.00 (IRR for mine type in Table IV, model 1) to 9.78 (IRR for mine type in Table IV, model 2) times higher probability for an underground coal mine to experience a case of pneumoconiosis during the 2006–2015 time period when compared to surface coal mines.

Table IV also shows that, for coal mines, each unit increase in an inspector observed instance of noncompliance with a management practice regulation, was associated with a 12% increase in the probability for that mine to report a case of pneumoconiosis. Finally, for coal mines, each increase in an inspector observed instance of noncompliance with an engineering control regulation was associated with a 10% increase in pneumoconiosis.[5,6]

4. DISCUSSION

Given the important need to better understand the trends and the efficacy of efforts to prevent lung diseases in the U.S. mining industry, the overall objectives of this study were twofold: (1) to derive an understanding of the trends of occupational lung diseases in the mining industry from data maintained by MSHA; and (2) to examine whether or not mines that consistently complied with a relevant subset of MSHA's health standards were associated with lower counts of lung diseases over time.

With respect to the first objective, the analysis revealed that cases of lung disease reported to MSHA occurred mostly in underground coal mines concentrated in the Appalachian region of the United States. The findings suggest that the probability of a coal mine reporting a diagnosed lung disease to MSHA during the 2006–2015 time period was approximately 16.00 to 17.80 times greater than the probability of a non-coal mine. Within the coal mine subsample, the probability of a mine reporting a lung disease was found to be greater for underground as opposed to surface types (by 2.73 to 3.40 times) and in the Appalachian region as opposed to the remaining regions of the United States (8.00 to 9.78 times).

In order to examine the second of the study's objectives, counts of mine-level lung diseases were merged with counts of MSHA inspector observed instances of noncompliance with lung disease prevention requirements associated with (1) engineering controls, and (2) management practices. As discussed, epidemiologic and empirical evidence suggests a 10-year time lag between a repeated exposure to hazardous concentrations of airborne contaminants and disease diagnosis—with the possibility of accelerated cases (diagnosis approximately 5 years) and others with >10-year time lag from exposure to diagnosis (Blackley et al., 2016; Cocco, 2003; Hurley et al., 1982; Leung et al., 2012; Steenland et al., 2001). The current study addressed this latency challenge by utilizing a study design that included a 20-year time period (1996–2015), a mean time lag of 10 years with the possibility of ±5 years, and a prerequisite that each mining establishment included in the analysis had to be active within both the time period of potential exposure and the time period in which counts of lung diseases were derived.

In regard to the study's second objective, the results demonstrate that mining establishments that did comply with the identified subset of relevant MSHA health standards experienced a substantially lower number of lung diseases over time. The findings suggest that a single unit increase of noncompliance with an engineering control requirement related to lung disease prevention (1996–2005) resulted in a 10% to 22% (coal sample vs. total sample) increased probability for a lung disease to be reported by that mine (2006–2015). Further, a single unit increase of noncompliance with a management practice requirement related to lung disease prevention resulted in a 12% to 14% increased probability of lung disease being reported during the subsequent time period. These findings suggest that disciplined efforts to comply with the relevant MSHA requirements can be an effective method to decrease the probability of lung diseases in miners over time.

Within the sample of mining establishments, documented instances of noncompliance with engineering requirements were correlated with instances of noncompliance with management practice requirements at $r = 0.40$, $p < 0.05$. This less-than-moderate correlation justifies their separation and the consideration of their unique effects. However, the results do not necessarily suggest that either an engineering or management practice compliance strategy should be utilized. Indeed, they are both part of a well-established, unitary

[5] Coefficients for both zero inflated negative binomial and standard negative binomial models were found to be consistent.

[6] In none of the models executed was a significant moderation of the effect observed through the inclusion of interaction terms between either of the two predictors of interest and commodity, mine type, and U.S. region. This suggests that there is no significant difference in the estimated incident risk ratios between U.S. coal and non-coal commodities within the total sample (reported in Table III), between the Appalachian and remaining U.S. regions within the coal subsample (reported in Table IV), or between underground and surface mines within the coal subsample (reported in Table IV).

hierarchy of hazard control approach in which every effort to eliminate or minimize the hazard through engineering must first be taken. Given the diverse processes, tasks, and work environments involved in mining, combined with the potential limitations to currently available engineering solutions that can effectively reduce airborne contaminants to healthy levels (Ren, Wang, Kang, & Lu, 2012), the continued need for ongoing general and task-specific monitoring for levels of airborne contaminants and the provision of personal respiratory protection devices where unhealthy levels exist is critical.

5. LIMITATIONS AND CONCLUSIONS

As with any study using publicly available surveillance statistics, the potential for underreporting of illnesses in the MSHA database is a primary limitation to this study. In addition, by examining the effects of compliance on lung disease prevention over time, only the minimum engineering and management practice standards were investigated. Mining organizations may engage in lung disease prevention activities that exceed these minimum requirements and future studies may be designed to investigate effects beyond the minimum.

Additionally, subjective variance in MSHA inspector enforcement decision rationales is possible. Therefore, a strictly controlled measure of actual workplace conditions and management practices was not possible with the use of MSHA compliance data. Although not a standardized measurement, given the implications of documented instances of noncompliance with minimum health requirements (e.g., possible monetary penalty, social sanctions, and organizational implications) along with the right for mines to contest, an acceptable level of confidence in the reliability in the recorded observations seems justified.

An additional limitation of this study is the possibility for miners to have moved from one mine to another between the time of exposure and the time of lung disease diagnosis. Although this possibility would most likely not influence the trends, a potential for workforce mobility to decrease the observed effects of compliance on lung diseases is acknowledged. Thus, in lieu of this limitation, conservative estimates of the relevant effect sizes are assumed. Further, in relation to this limitation, injuries and illnesses related to contractors (the most extreme form of worker mobility within the mining industry) are not included.

Also noteworthy, given the lack of empirical evidence underpinning an understanding of the organizational contexts that precede occupational lung disease in the mining industry—along with a lack of previous similarly situated research—this study utilized a broad-based approach to categorize the MSHA standards used. Although the authors derived homogeneous categories of standards, future studies may be designed to more precisely steer prevention inquiries by narrowing relevant subsets of requirements in relation to a given context.

Finally, the findings of this study cannot be used to make inferences regarding the appropriateness of the established regulatory levels of airborne contaminants. It is possible that changes in permissible levels of airborne contaminants since 2005 (e.g., a recent reduction in the dust exposure limit) may alter the effects over time—which future studies may endeavor to explore.

Given these limitations, studies designed to examine the organizational contexts that precede lung diseases in the mining industry are rare. The long latency period (of 10 or more years of exposure) and the need to have indicators of the workplace conditions and practices that precede diagnosis by many years, research design challenges, and a lack of multidecade surveillance data are the likely sources of this gap. This study represents one of the few investigations that empirically reveals the efficacy of important and actionable organizational strategies designed to prevent occupational lung diseases.

ACKNOWLEDGMENTS

We are grateful to Emily Haas, Brent Doney, and David Weissman for their thoughtful reviews and comments. The findings and conclusions in this report are those of the author(s) and do not necessarily represent the official position of the National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention.

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