Accident Analysis and Prevention 50 (2013) 778–786

Contents lists available at SciVerse ScienceDirect

Accident Analysis and Prevention

journal homepage: www.elsevier.com/locate/aap

Profitability and occupational injuries in U.S. underground coal mines☆

Abay Asfaw[a,*], Christopher Mark[b], Regina Pana-Cryan[a]

[a] *Centers for Disease Control and Prevention (CDC), National Institute for Occupational Safety and Health (NIOSH), Washington, DC, United States*
[b] *Coal Mine Safety and Health-Mine Safety and Health Administration (MSHA), Pittsburgh, PA, United States*

ARTICLE INFO

Article history:
Received 19 March 2012
Received in revised form 8 June 2012
Accepted 1 July 2012

Keywords:
Underground mines
Profitability
Injury
Negative binomial
Panel data

ABSTRACT

Background: Coal plays a crucial role in the U.S. economy yet underground coal mining continues to be one of the most dangerous occupations in the country. In addition, there are large variations in both profitability and the incidence of occupational injuries across mines.
Objective: The objective of this study was to examine the association between profitability and the incidence rate of occupational injuries in U.S. underground coal mines between 1992 and 2008.
Data and method: We used mine-specific data on annual hours worked, geographic location, and the number of occupational injuries suffered annually from the employment and accident/injury databases of the Mine Safety and Health Administration, and mine-specific data on annual revenue from coal sales, mine age, workforce union status, and mining method from the U.S. Energy Information Administration. A total of 5669 mine-year observations (number of mines × number of years) were included in our analysis. We used a negative binomial random effects model that was appropriate for analyzing panel (combined time-series and cross-sectional) injury data that were non-negative and discrete. The dependent variable, occupational injury, was measured in three different and non-mutually exclusive ways: all reported fatal and nonfatal injuries, reported nonfatal injuries with lost workdays, and the 'most serious' (i.e. sum of fatal and serious nonfatal) injuries reported. The total number of hours worked in each mine and year examined was used as an exposure variable. Profitability, the main explanatory variable, was approximated by revenue per hour worked. Our model included mine age, workforce union status, mining method, and geographic location as additional control variables.
Results: After controlling for other variables, a 10% increase in real total revenue per hour worked was associated with 0.9%, 1.1%, and 1.6% decrease, respectively, in the incidence rates of all reported injuries, reported injuries with lost workdays, and the most serious injuries reported.
Conclusion: We found an inverse relationship between profitability and each of the three indicators of occupational injuries we used. These results might be partially due to factors that affect both profitability and safety, such as management or engineering practices, and partially due to lower investments in safety by less profitable mines, which could imply that some financially stressed mines might be so focused on survival that they forgo investing in safety.

Published by Elsevier Ltd.

1. Introduction

Coal plays a crucial role in the U.S. economy. In 2009, 1.1 billion tons of mined coal produced more than half of all the electricity used in the country and generated more than $4 billion in export revenue. During the same year, approximately 90,000 workers were employed in coal production, more than half of whom worked underground (United Mine Workers of America, n.d.; PBS, n.d.; Energy Information Administration (EIA), 2010).

Underground coal mining has been and remains one of the most dangerous occupations in the country (Zimmerman, 1981; Bennett and Passmore, 1984; Reardon, 1993; Toscano and Windau, 1993; Kowalski-Trakofler et al., 2005; Esterhuizen and Gürtunca, 2006). In recent years, the fatal occupational injury rate in underground coal mining has been six times higher than that in all private industry (CDC, 2001; Groves et al., 2007; Bureau of Labor Statistics (BLS), 2010). Studies have also shown that the costs associated with occupational fatal and nonfatal injuries in coal mines have been increasing (BLS, 2007; National Institute for Occupational Safety and Health (NIOSH), 2008; Margolis, 2010; Moore et al., 2010).

Several explanations for the high number of injuries occurring in some mines have been proposed in the literature, including geological factors such as low seam height (Boden, 1985; Fotta and Mallett, 1997), room-and-pillar mining method (Pfleider and Krug, 1973; Boden, 1985; Pappas et al., 2003), small mine size (The

---

☆ *Disclaimer*: The findings and conclusions in this paper are those of the authors and do not necessarily represent the views of the National Institute for Occupational Safety and Health or the Mine Safety and Health Administration.

* Corresponding author.
E-mail address: hqp0@cdc.gov (A. Asfaw).

0001-4575/$ – see front matter. Published by Elsevier Ltd.
http://dx.doi.org/10.1016/j.aap.2012.07.002

President's Commission on Coal, 1980; National Research Council, 1982; Fotta and Mallett, 1997; Grayson, 2001), nonunionized workforce (National Research Council, 1982; Appleton and Baker, 1984; Morantz, 2011), less experienced and younger miners (Hull et al., 1996; Margolis, 2010), inadequate miner training (Dames and Moore, 1977; FlorJancic, 1981; Zimmerman, 1981), incomplete understanding of the return on safety investments (Brody et al., 1990), inadequate safety regulations (The President's Commission on Coal, 1980; Mendeloff, 1980; FlorJancic, 1981; Neumann and Nelson, 1981), and no prior experience with disaster (Madsen, 2009). Some of these factors, such as geological conditions, mining method, and mine size, might reflect how "easy to mine" a particular mine might be. In addition, differences in the level of investment in occupational injury prevention might explain some of the variation in the incidence rate and severity of injuries among underground coal mines.

The link between the financial strength of mines and the incidence of occupational injuries has been explored through the correlation between productivity and safety in at least two major studies by the National Research Council (1982) and Grayson (2001). While these studies supported the industry belief that "a productive mine is a safe mine," their findings were not very robust after controlling for other variables. One possible explanation may be that productivity, measured in tons of coal produced per hour, is an imperfect measure of a mine's financial strength. For example, in 2009, the average price of underground coal was $32.32/ton in Utah, while it was $78.75/ton in Virginia (EIA, 2010). Therefore, a mine in Virginia that is less *productive* than a mine in Utah might actually be more *profitable* than the mine in Utah.

Financially strong mines can reduce the incidence of occupational injuries by investing more in worker safety. For example, they can more easily improve the overall mining system, hire experienced workers, and provide comprehensive safety training to their workers than mines that are struggling to survive. There is evidence that investments in safety can boost the profitability of mines by lowering several categories of employer costs, such as insurance and wage premiums, workers' compensation benefit payments, and frequent production disruptions associated with injuries (Brody et al., 1990; Cutler and James, 1996; Yakovlev and Sobel, 2010; Moore et al., 2010). Similar results have also been reported in other industries such as nuclear power plants (Waddock and Graves, 1997).

If a mine is not financially strong, however, employers might not believe they can afford to invest in occupational injury prevention, especially if the injuries targeted by the investment have a relatively low expected probability of occurring in the absence of prevention (Hopkins, 1999). This means that less profitable mines might not shift scarce financial resources from producing coal to investing in occupational injury prevention because the short-term benefits might not seem to exceed the costs of prevention. As a result, less profitable mines might be less likely to invest as much in safety as more profitable mines would.

In this study, we examined whether the profitability of underground coal mines was associated with the incidence rate of occupational injuries. We hypothesized that, after controlling for mine age, workforce union status, mining method, and geographic region, the incidence rates of all reported injures, reported injuries with lost workdays, and the most serious injuries reported would be higher in less profitable mines.

2. Methods

When using discrete and non-negative data, such as number of injuries, it is common to use count data models, such as Poisson or negative binomial. To determine which model to use, we examined the fitness of each distribution to our dependent variables. Fig. 1 presents the fitness of the Poisson and the negative binomial models using the number of all injures as an example. Details about the data used are provided in Section 3.

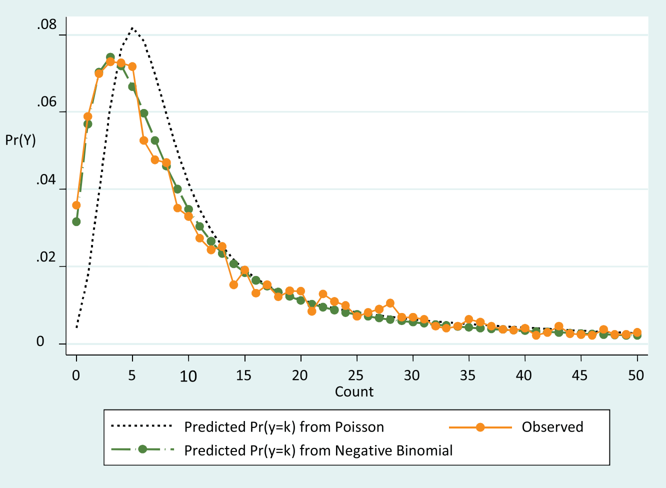

Fig. 1. Comparison of the negative binomial and Poisson models: all reported injuries in the 5669 mine-year records used.

The Poisson model often does not fit actual data well due to its assumptions of equidispersion and independence of events. In our case, the Poisson model underestimates the predicted number of mine-year observations with no injury events. We used the negative binomial model because it fit all the dependent variable indicators we used better than the regular Poisson model.

While count data models treat injury variables as being independent across time, mine-specific variables, such as geological conditions and management practices, are more likely to be serially correlated. Therefore, we used a count data model for panels – that include cross-sectional and time-series data – with N number of mines and T number of years. In addition to controlling for observable individual mine heterogeneity, such as individual mine-specific characteristics that may include size, age, and mining method, analyzing panel data enables us to control for unobservable heterogeneity among individual mines (see for instance, Hsiao, 2003; Baltagi, 2009).

We assumed that each injury variable indicator (y_{it}) takes a value of 0, 1, 2, 3, . . ., varies among mines i ($i = 1, \ldots, N$) and over time t ($t = 1, \ldots, T$), and has a negative binomial distribution that allows its variance to be greater than its mean. Following Hausman et al. (1984), the random effect overdispersion can be specified as:

$$Pr\left(Y_{it}=\frac{y_{it}}{\mathbf{x}_{it}},\delta_i\right)=\frac{\Gamma(\lambda_{it}+y_{it})}{\Gamma(\lambda_{it})\Gamma(y_{it}+1)}\left(\frac{1}{1+\delta_i}\right)^{\lambda_{it}}\left(\frac{\delta_i}{1+\delta_i}\right)^{y_{it}} \qquad (1)$$

where

$$\lambda_{it}=E\left(\frac{y_{it}}{\mathbf{x}_{it},\delta_i}\right)=\exp(\mathbf{x}'_{it}\boldsymbol{\beta}) \qquad (2)$$

and $\mathbf{x}_{it}$ is a matrix of explanatory variables, $\boldsymbol{\beta}$ is a matrix of coefficients to be estimated, Γ is the gamma function, and δ_i is the dispersion parameter. The mean and variance of y_{it} are given by:

$$E(y_{it})=\delta_i\lambda_{it} \qquad (3)$$

and

$$var(y_{it})=(1+\delta_i)\delta_i\lambda_{it} \qquad (4)$$

Eqs. (3) and (4) indicate that the mean to the variance ratio is $1/(1+\delta_i)$, which can vary across mines but is constant through