10

The MINER Act of 2006: Innovating for Safety and Health in US Mining

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Disclaimer: The views expressed in this article are the authors' and do not necessarily represent the views of the United States Patent and Trademark Office. The authors would like to thank Reza Noorani, Mine Safety and Health Administration, US Department of Labor, for providing the US mine accident data used in this chapter and Alexander Giczy for excellent research assistance.

10.1 Introduction

Mineral mining jobs are among the most dangerous in the world. According to the International Labour Organization, mining accounts for about 8 percent of the world's work-related fatalities but only represents 1 percent of the global workforce (ILO, 2015). However, while mining is unquestionably a dangerous industry, the long-run trend in the United States (USA) shows a significant decline in mine-related fatalities. US fatalities peaked in 1917 at 3,679 people. This total includes a disastrous electrical fire at Granite Mountain's Speculator Mine that resulted in 163 deaths. By 1954, the number of annual fatalities had dropped to 535 people and continued to fall to 28 by 2017. This long-run decrease surely reflects a number of changes, but technological innovations are likely to be one of the most important sources of improvements in health and safety outcomes at US mining operations.

This chapter uses patent data to explore the levels and trends in technological innovations in US mineral mining with a particular focus on safety and health. Starting with the World Intellectual Property Organization (WIPO) set of mining patents discussed earlier in this volume, our chapter introduces a modern data refinement for grouping patents into thematic areas or industries, so-called patent landscaping. We apply a machine-learning approach to identify patents granted by the US Patent and Trademark Office (USPTO) related to mineral mining as well as those patents directed at technical innovations in mine safety.

After forming our patent database using the machine-learning approach, our chapter focuses on the impact of the Mine Improvement and New Emergency Response (MINER) Act of 2006. With this Act, the US Congress tried to mitigate risks in underground mining and to ensure worker safety. Importantly, the Act created a competitive grant program to stimulate mine safety- and health-related innovations. We present four types of evidence on the impact of the MINER Act: graphical, case studies, text-based similarity and regression analysis. While this evidence does not include a randomized or natural experiment to establish causality, all four types of evidence point to a positive and significant effect of the MINER Act on patenting in safety-related mineral mining technologies, as well as reduced injuries and lost workdays among mine workers.

Section 10.2 provides a quick overview of the major US laws related to mining safety and health and describes the 2006 MINER Act. Section 10.3 describes our machine learning approach to identifying mineral mining patents and the subgroup related to safety[1]. Section 10.4 gives a brief overview of our data on mineral mining while Section 10.5 contains the evaluation of the MINER Act using our patent database. Concluding remarks appear in Section 10.6.

10.2 Health and Safety Legislation in US Mining

Mineral mining has always played a key role in US economic activity. In 1900, US production of metallic and nonmetallic minerals amounted to over $1 billion (equivalent to over $29 billion in 2017 dollars) (Day, 1902). Moreover, despite some important downturns, the role of mineral mining and its share in US economic activity has seen dramatic increases throughout the twentieth century. In 2017, total mineral mining production in the USA reached nearly $100 billion (Ober, 2018).

Similarly, mineral mining has contributed significantly to employment in the USA. As shown in Figure 10.1, at its peak in 1923, the mineral mining industry employed over 860 thousand miners. While we observe continuing decline in mineral mining jobs, primarily due to

[1] See Toole et al. (2019) for technical details on the machine-learning approach.

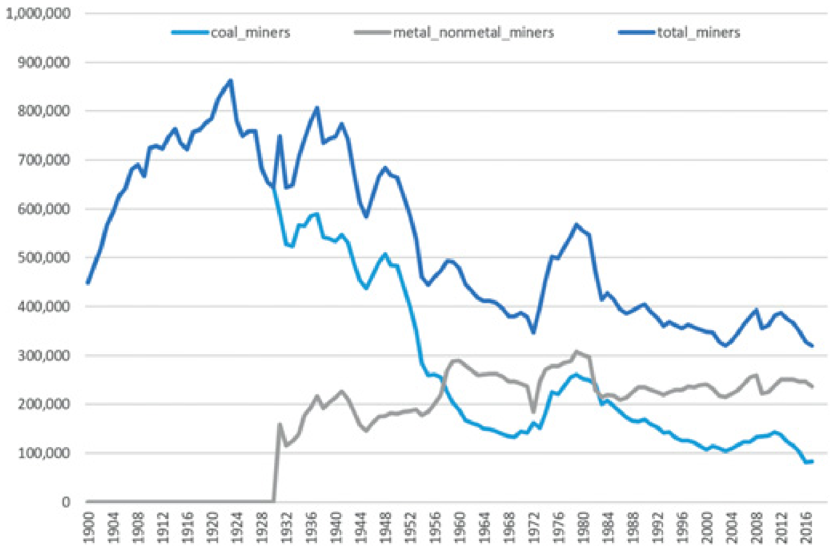

Figure 10.1 US mining employment (1900–2017)
Source: www.cdc.gov/niosh/mining/data/default.html

technological advances, the mining industry remains a major employer with nearly 320 thousand miners employed in the USA in 2017.

Unfortunately, mineral mining is also an inherently dangerous job that exposes miners to high risks of accidents that are sometimes fatal. Each mining accident can have disastrous consequences, claiming the lives of hundreds of miners in a single instance. As shown in Figure 10.2, the highest number of fatalities occurred in 1917 when 3,679 miners lost their lives due to mining accidents.

The dangerous nature of mineral mining activities prompted the US federal government to enact laws aimed at improving the safety and health of miners. The following provides a short synopsis of the US legislative history leading up to the 2006 MINER Act, which is the main focus of our analysis.

- The first safety and health-related Congressional initiative became law in 1891. Among other things, this federal statute established minimum ventilation requirements at underground coal mines and prohibited the employment of children under 12 years of age.
- In 1910, in light of the rising fatality rates in the previous decade, Congress established the Bureau of Mines as an agency in the

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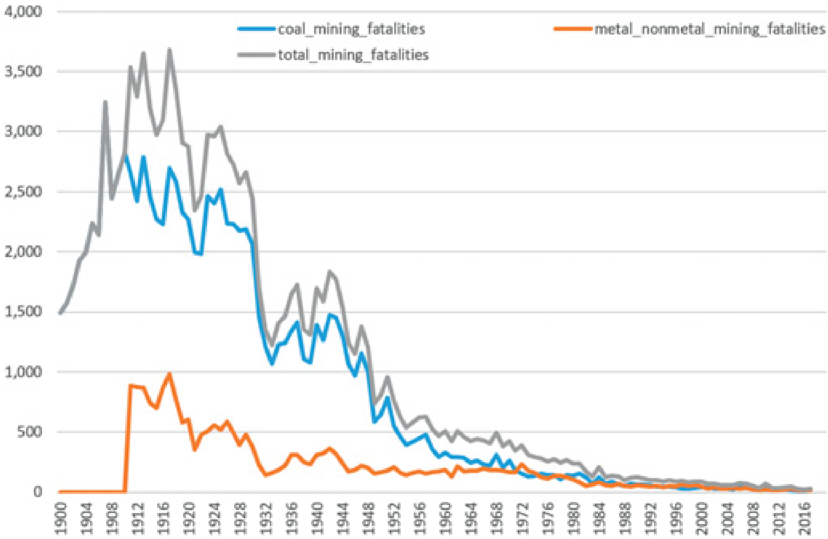

Figure 10.2 Fatalities in US mining (1900–2017)
Source: www.cdc.gov/niosh/mining/data/default.html

Department of the Interior. Led by Dr. Joseph A. Holmes as its first director, the Bureau was responsible for research and the reduction of accidents in coal mining. The Bureau focused on training and educational efforts and successfully trained over 50 thousand miners in its first year on first aid, mine rescue, and fire-fighting skills.

- The Federal Coal Mine Safety Act was passed in 1952. This statute, and its more comprehensive 1966 version, provided for annual inspections of coal mines, gave the Bureau of Mines additional enforcement authority, including issuing violation notices and withdrawal orders, and authorized the assessment of civil penalties against noncomplying mine operators.
- In 1966, the Federal Metal and Nonmetallic Mine Safety Act became the first federal statute directly regulating non-coal mines. Although it gave only minimal enforcement authority to the Bureau, the statute called for advisory standards and allowed for inspections and investigations of non-coal mines (Breslin, 2010).
- A few years later, Congress passed the Federal Coal Mine Health and Safety Act of 1969 (known as the Coal Act). Up to that date, this was the most comprehensive and stringent mining law targeting safety. Among other things, the Coal Act significantly increased the

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enforcement authority of federal agencies, required the imposition of monetary penalties for all violations, and established criminal penalties for knowing and willful violations.

- A year later, in 1970, Congress passed the Occupational Safety and Health Act, which created the National Institute for Occupational Safety and Health (NIOSH). This newly created agency has the mandate to "conduct . . . research, experiments, and demonstrations relating to occupational safety and health" and to develop new methods and approaches increasing occupational safety and health. While not intended exclusively for the mining industry, NIOSH has contributed and continues to contribute significantly to the advancement of health and safety in mining.
- In 1977, Congress again passed a statute regulating health and safety in mining, the Federal Mine Safety and Health Act, also known as the Mine Act. It amended the 1969 Coal Act and consolidated all federal health and safety regulation in mining. This statute also transferred responsibilities from the Department of the Interior to the Department of Labor and called the new agency the Mine Safety and Health Administration (MSHA). Along with the new agency, the statute created a committee that provides an independent review of MSHA's enforcement actions. Furthermore, the Mine Act gave miners stronger and broader rights with enhanced protection from retaliation for exercising these rights.

From 1977 to 2005, the US Congress did not pass any new mining legislation related to safety and health. However, things changed in 2006. On the morning of January 2, 2006, West Virginia suffered its worst mining disaster in over half a century due to a coal mine explosion in the Sago Mine. Located near the Upshur County seat of Buckhannon in Sago, West Virginia, the mine had an explosion followed by a collapse that trapped 13 miners. Only one survived. A few days later, on the morning of January 19, 2006, another mine accident in West Virginia claimed two more lives. In this case, a conveyor belt in the Aracoma Alma Mine in Logan County, West Virginia, caught fire releasing a heavy cloud of smoke. The two miners died of carbon monoxide poisoning. A few months later on May 20, 2006, another mine disaster killed five more miners. This time the accident was at the Darby Mine in Harlan County, Kentucky, where an explosion that investigators attribute to methane occurred with only one survivor.

Spurred by these tragedies, the Health, Education, Labor, and Pensions (HELP) Committee in the US Senate spearheaded an initiative to manage risks in underground coal mining and to ensure worker safety. The HELP Committee identified six areas of particular concern: post-accident communication, post-accident tracking, post-accident breathable air, lifelines for use in post-accident escape, training and local emergency coordination (Breslin, 2010, p.5). They believed improvements in mine safety were possible through "innovation, vigilance, adaptability and resources."

On June 15, 2006, President George W. Bush signed the resulting Congressional bill to pass the MINER Act. One of the most important sections of this law, section 6, permanently established the Office of Mine Safety and Health within the National Institute for Occupational Safety and Health (NIOSH). The purpose of this new office was "to enhance the development of new mine safety technology and technological applications and to expedite the commercial availability and implementation of such technology in mining environments."[2] To fulfill this purpose, the Office was to establish a competitive financial award program to facilitate research, development, and testing of new technologies and equipment. This new technology-oriented public financing program could award grants or contracts to research institutions or private companies to stimulate new mine safety technology and equipment. Within 10 years of the passage of the MINER Act, the Office of Mine Safety had awarded over "120 technology development and commercialization or interagency agreements in its execution of the MINER Act."[3]

The MINER Act is the primary focus of the empirical work in this chapter. Our objective is to evaluate the evidence that the 2006 MINER Act improved US miner safety and health.

10.3 Data Sources and Data Processing

As described in Daly et al. (2019), the World Intellectual Property Organization (WIPO) developed an algorithm that identified the set of global patents (applications and grants) related to mineral mining. This effort exploited the European Patent Office's PATSTAT product and used a traditional patent landscape methodology. Specifically, WIPO identified patent documents that correspond to mineral mining

[2] www.govinfo.gov/content/pkg/CRPT-109srpt365/html/CRPT-109srpt365.htm
[3] www.cdc.gov/niosh/mining/researchprogram/contracts/index.html

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inventions based on detailed technology classification codes (from the International Patent Classification system) and Boolean text-based searches of patent document titles and abstracts. WIPO applied these methods to PATSTAT and identified over 1.6 million patent applications. Of these 1.6 million patent applications, which cover a variety of countries, we determined that 123,853 of these applications were submitted to the USPTO with application dates reaching as far back as the early 1960s.

As described in Toole et al. (2019), we used a machine-learning approach to refine the original WIPO patent dataset. This approach improves on the traditional patent landscape methodologies by more fully exploiting the rich text-based information contained in published patent documents (i.e. patent specifications). We augmented the traditional approach with machine learning to identify US patents granted in the area of mineral mining and in the subarea of safety-related patents in mineral mining. In this section, we provide a high-level overview of our approach and data.

Starting with the US applications contained in the WIPO patent dataset (123,853), we used the patent application numbers to match to PatentsView, which is a public visualization and analysis tool for US-granted patents (www.patentsview.org). We determined that 91,818 of the 123,853 unique US patent applications were granted and the remaining 32,035 were published applications without a corresponding patent number.[4] Inspection of these 91,818 patents revealed a fairly large number of patents that did not belong in a group of mineral mining patents.[5] We found patents directed toward technology improvements related to oil & gas wells, robotic household vacuums, data mining techniques, nucleotide sequences (including amine groups) and motorcycle fuel pumps.

Based on this, we developed a machine-learning approach to refine our set of US-granted patents in mineral mining (see Toole et al. (2019) for details).[6] This involves three steps: (1) identifying a "training set" of

[4] We assume that the applications with no patent number have not been granted. Either these applications have been abandoned or they are still undergoing the patent examination process.

[5] We defined "mineral mining" patents as those directed to an improvement related to the extraction or refinement of either minerals (both metallic and nonmetallic minerals) or coal.

[6] Of the 92k patents, we could only use those that had patent owners identified in the data. This was 78,173 (85.1 percent).

patents; (2) allowing a computer algorithm (i.e. a machine-learning statistical procedure) to learn how to identify mineral mining patents from the training set; and (3) using the machine-learning results to classify patents into mineral mining and nonmineral mining. The training set is a group of patents that we identified as mineral mining and nonmineral mining. We formed a training set of 22,813 patents using a variety of information and manual checking. Then, based on statistical performance criteria, we decided on a machine-learning algorithm.[7] Finally, we then applied the machine-learning results to classify each of the remaining 68,503 patents from the WIPO patent dataset, which resulted in classifying 43,815 patents as mineral mining patents and 24,688 patents as nonmineral mining.[8] Our final dataset of US patents granted in mineral mining contains 45,572 patents (43,815 + the mineral mining patents from the training set of 1,757) out of the 91,818 patents from the WIPO Patent Dataset.

To determine safety-related mineral mining patents, we undertook another three-step process (see Toole et al. (2019) for a detailed description). First, we applied Boolean searches to identify a starting group. This is the traditional patent landscape method. Second, we refined this set based on language in the patent documents. The patent language was analyzed using an established multi-task convolutional neural network classifier. Third, we restricted our set of safety-related mineral mining patents to those appearing in our refined version of WIPO's patent dataset described previously. This intersection produced 1,311 patents – our final group of US granted patented for safety-related mineral mining.

10.4 US Patents in Mineral Mining

While imperfect, economists and policy makers often use patents as an indicator of innovation. The rationale is that patented technologies often facilitate or are used to define and construct new products and services. Taking this perspective, the level and trend in granted patents can provide information on the technological evolution of an industry, even its "innovativeness."

Figure 10.3 provides a perspective on innovation in mineral mining using our refined dataset of 45,572 US patents. The patents are displayed

[7] We used a linear Support Vector Machine classifier with stochastic gradient descent.

[8] We could not run 527 patents through the classifier because their specification text was missing in the data.

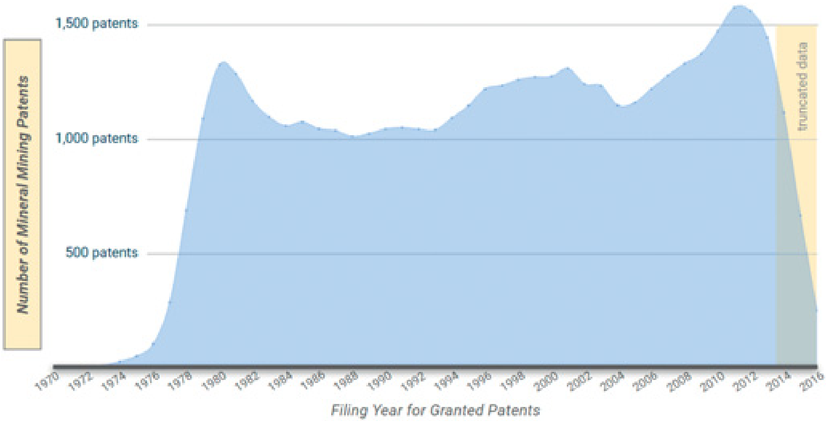

Figure 10.3 USPTO-granted patents in mineral mining (three-year moving average by filing year)
Source: Author's calculations.

by filing date to better reflect the date of invention discovery. We also use a three-year moving average to smooth the time series. It is clear from the figure that our coverage is most comprehensive for patents filed during the period 1979–2014.[9] During that period, we observe that filing rates were over 1,200 applications annually. We also observe an overall increase in the filing rates with a peak of 1,616 patent filings in 2012. This shows that innovation in the US mining industry remains strong and is even increasing. We show later that a number of these innovations reflect a significant rise in safety-related mineral mining patents, particularly following the 2006 MINER Act.

10.5 The MINER Act of 2006: Safety Innovation and Health Outcomes

In this section, we explore the impacts of the 2006 MINER Act on innovation in mineral mining safety and health. We present four types of evidence: graphical, case studies, text-based similarity and regression analysis. While this evidence does not include a randomized experiment or natural experiment to establish causality, all four types of evidence point to a positive and significant effect of the MINER Act on patenting

[9] Our data provides limited coverage of earlier years and suffers from truncation in later years. Note that we report a three-year moving average to focus on overall trends.

in safety-related mineral mining technologies as well as reduced injuries and lost workdays among mine workers.

10.5.1 Graphical Evidence

Figure 10.4 presents our primary graphical evidence. It displays the set of 44,261 mineral mining patents and our subset of 1,311 safety-related mineral mining patents to visualize how each has changed across time.[10] To minimize volatility and focus on the trend, we report three-year moving averages by patent filing dates. The critical comparison is between the broad group of mineral mining patents and the safety-related subgroup. The broad group experienced a wave of new patent filings starting around 1995 and ending in 2003, while safety-related patent filings declined over this period. If one looks at the window of time around the 2006 MINER Act, the period from 2004 to 2012, mineral mining patent filings increased by 36 percent, but safety-related patent filings grew by 113 percent. That is, the filing rate for

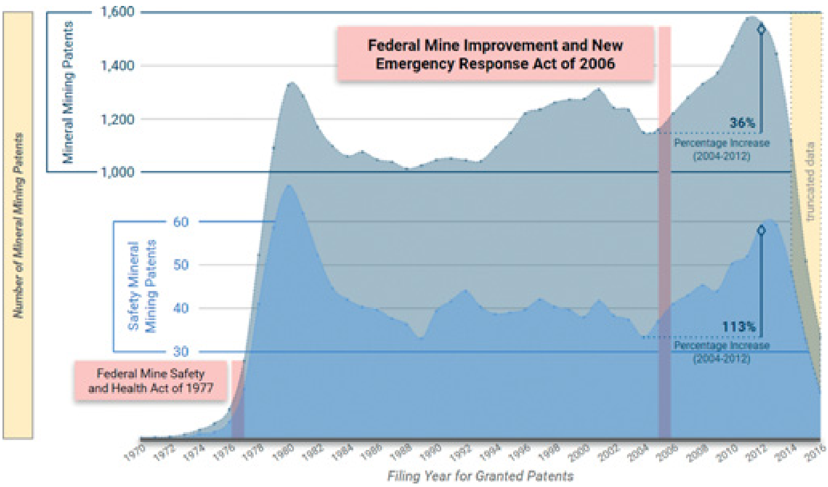

Figure 10.4 USPTO-granted patents in mineral mining separated into safety-related and non-safety-related groups (three-year moving average by filing year)
Source: Author's calculations.

[10] The 44,261 mineral mining patents in this set exclude the 1,311 mineral mining safety patents (i.e. 45,572 – 1,311 = 44,261).

safety-related mineral mining patents increased by more than triple other mineral mining patents for the same period. This evidence suggests that the 2006 MINER Act stimulated growth in safety-related patenting. The growth rate difference between these two groups can be loosely interpreted as the "treatment effect" from the MINER Act. It suggests the MINER Act led to a 77 percent increase in safety-related USPTO patent filings. While this point estimate is probably too high, the effect of the MINER Act appears to be positive and economically meaningful.

We also examined two key technologies relevant to the 2006 MINER Act that relate to improvements in accident preparedness and emergency responsiveness. In particular, the Act specifically mentions the need for more effective means of *through-the-earth communication* for trapped miners and *refuge chambers* in which miners can safely wait.[11] These two areas are defined as:

(1) **Refuge Chambers**

- An emergency shelter installed in an underground mine intended to provide mine workers access to clean air, food, and water until they can be rescued.[12]

(2) **Two-way, 'through-the-earth' (TTE) wireless communications**

- A wireless communication through the earth surface under which a miner is trapped and where regular radio transmissions cannot operate.[13]

To evaluate the extent to which the MINER Act helped advance innovation in these two areas, we identified all of the keyword occurrences for "refuge chamber" and "TTE communication" for the period before and after the Act. We conducted keyword searches on all 45 k mineral mining patents in our dataset as follows:

- The keywords used to identify refuge chamber related mineral mining are: "refuge chamber"; "refuge shelter"; "refuge alternative"; "emergency

[11] For more detail, see sections 2, 6 and 13 of the MINER Act. file:///C:/Users/atesfayesus/Desktop/All%20Files/Projects/Early%20Projects/Mining/Legislative%20History/2006mineract.pdf

[12] www.cdc.gov/niosh/mining/topics/refugechambers.html

[13] No suitable through-the-earth technologies (for communication between underground miners, mine rescue teams, and a surface command center) existed when the MINER Act was enacted. www.cdc.gov/niosh/mining/features/throughtheearthcommtech.html

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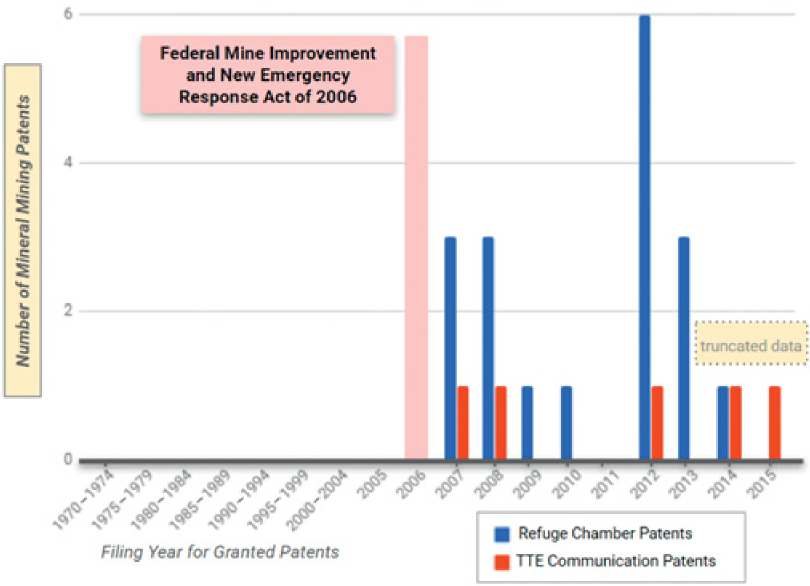

Figure 10.5 USPTO-granted patents in mineral mining for refuge chambers and TTE communications
Source: Author's calculations.

shelter"; "emergency chamber"; "rescue shelter"; "outby refuge"; "outby shelter"; "hardened room"; "in place shelter".[14]

- The keywords used to identify TTE communication related mineral mining are: "through the earth" and any["tte," "(tte)," "'tte'"].[15]

As shown in Figure 10.5, we find that all of the patenting activity in both areas occurred after the MINER Act in 2006. There were eighteen patent filings related to "refuge chamber" (shown in blue) filed in 2008 or later. Similarly, five patents related to "TTE communication" (shown in red). Again, we find that all of these patents were filed in the period after the MINER Act.

[14] We selected these keywords using two NIOSH publications as reference: www.cdc.gov/niosh/mining/works/coversheet1695.html; www.cdc.gov/niosh/mining/Works/coversheet1886.html

[15] These selections rely on NIOSH-sponsored research paper summarizing TTE wireless communication (Yenchek et al., 2011)

10.5.2 Case Studies

Case Study #1: *Battelle Memorial Institute & Emergency Mine Refuge Alternatives*
Battelle is a private nonprofit applied science and technology company headquartered in Columbus, Ohio, and founded in 1929. Initially funded by Ohio industrialist Gordon Battelle, the original focus was research, development and commercialization of metals and material science technology. Battelle has expanded to offer solutions in medical devices, public health and safety, agrifood, industrial products, pharmaceutical and biotechnology, and national laboratory management.

Event Timeline

February 2006: One month after the tragic Sago Mine disaster, Ohio formed the *Underground Mine Task Force* to evaluate Ohio's underground mine emergency response program. Subject-matter experts were invited to give presentations on state-of-the-art safety equipment and technological advancements. **Battelle's Jim Reuther and Rick Givens** gave a presentation on **a new type of mine refuge alternative**: *"Breathing Curtain: New Mine-Fire Survivor Rescue Tool."*

August 2007: Battelle was awarded a NIOSH grant to further develop, design and demonstrate its new mine refuge alternative. At contract completion, Battelle was pursuing commercialization and field testing of the prototype in an operating underground coal mine.[16]

June 2013: The US Patent & Trademark Office granted a patent[17] to Battelle for a "Mine Barrier Survival System," wherein both Jim Reuther and Rick Givens were included as inventors.

Technology Description (Figure 10.6)

How It Works: After an explosion or collapse, miners unroll, inflate and connect lightweight plastic alls (see Item 100 in Figure below) in order to create a wall-to-wall barrier (400). Two wall-to-wall barriers are erected in order to provide safe volume (410) for the survivors. In this safe space, breathable, filtered-air (CO_2 absorption, O_2 generation, CO reduction, flammable methane reduction) is provided by a unique air-scrubbing system attached to the inside walls of the inflatable barriers.

16 www.cdc.gov/niosh/mining/researchprogram/contracts/contract_200–2007-22067.html
17 US Patent 8,469,781 had the highest avg. refuge cosine similarity score of the identified WIPO refuge chamber patents.

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Case Study #2: *Stolar, Inc. & TTE Emergency Communications*

Stolar is a research and development company based in Raton, New Mexico, and founded in 1983 by Dr. Larry Stolarczyk. Stolar specializes in radio geophysics development for the underground mining industry with the mission to improve underground coal mining health, safety and productivity.

Event Timeline

1980s: Starting in the early 1980s, the New Mexico company pioneered the development of through-the-earth imaging of coal seams using electromagnetic waves.

January 2006: A methane gas explosion in the Sago Mine trapped its miners without a way to communicate with surface personnel 85 m (280 feet) above. The trapped miners believed that the mine's escape-way was blocked. If communications had been available, the miners could have been given instructions for a 700-foot walk to fresh air.[18] Only 1 of the 13 trapped miners survived.

March 2006: In response to both the tragic Sago Mine and Aracoma Alma No.1 Mine fatalities in January 2006, the Mine Safety and Health Administration (MSHA) held a "Mine Rescue Equipment and Technology Forum" in Washington, DC. At the forum, **Stolar** gave a presentation on a new, proposed emergency communication and tracking system utilizing ultra-low frequency (ULF) radio waves that can travel up, through the earth, to a surface receiver.

June 2006: The Mine Improvement and New Emergency Response Act (the "MINER Act") was enacted, and called for underground coal mines to develop post-accident emergency response plans that specify two-way wireless communications and electronic tracking systems. "No suitable through-the-earth (TTE) communication systems existed when the MINER act was enacted."[19]

September 2009: Stolar was awarded a NIOSH contract to design a two-way, TTE emergency communication system, fabricate the hardware and test the prototype. A demonstration in a southwestern Pennsylvania commercial coal mine achieved two-way text messaging at a vertical range of nearly 244 m – with an extrapolated maximum vertical range at this mine site of nearly 335 m.[20]

September 2013: The US Patent and Trademark Office granted a patent[21] to Stolar for an improved underground radio communications and tracking system.

[18] www.cdc.gov/mmwr/preview/mmwrhtml/mm5751a3.htm

[19] www.cdc.gov/niosh/mining/features/throughtheearthcommtech.html

[20] www.cdc.gov/niosh/mining/researchprogram/contracts/contract_200–2009-32117.html

[21] US Patent 8,115,622 holds the highest avg. TTE cosine similarity score in the WIPO dataset.

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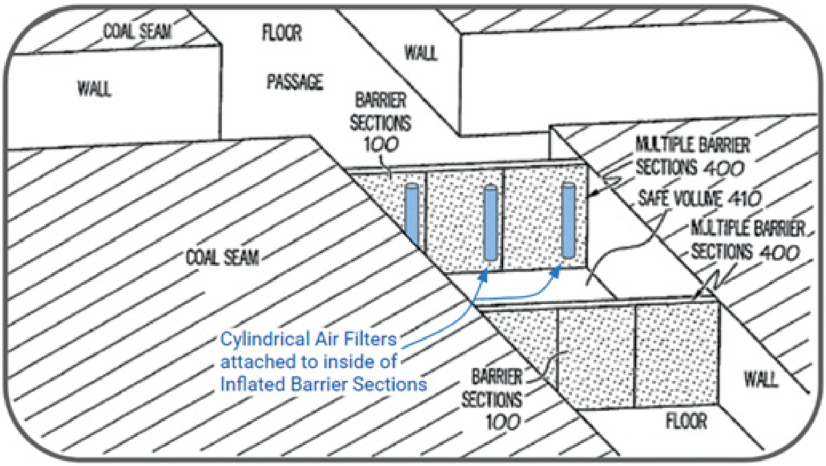

Figure 10.6 Schematic diagram of a wall-to-wall barrier in a passageway of a mine
Source: Author's calculations, based on Figure 4 in US Patent 8,469,781.

Technology Description (Figure 10.7)

How It Works: A software definable transceiver integrated into the cap lamp of a mining hardhat allows a miner to communicate via voice or text-message using carrier waves ranging from ultra-low frequency (suitable for sending/receiving through-the-earth text messages) to ultra-high frequency (suitable for voice calls). Additionally, a Blackberry-type PDA can be connected to the hardhat transceiver via Bluetooth so as to enable the miner to receive and view foreman's reports, maintenance advisories and location information of mine assets and roaming miners on the PDA display.

10.5.3 Text-Based Similarity

Another approach to explore the impact of the 2006 MINER Act on innovation in mineral mining safety and health relies on establishing a link between innovation efforts driven by the MINER Act and patenting activity. Recall that the Act established a competitive funding program administered by National Institute of Occupational Safety and Health (NIOSH). We analyzed all 105 awarded NIOSH mining safety contracts to determine which of our 45 k mineral mining patents contained similar language to the awarded NIOSH mining safety contracts.

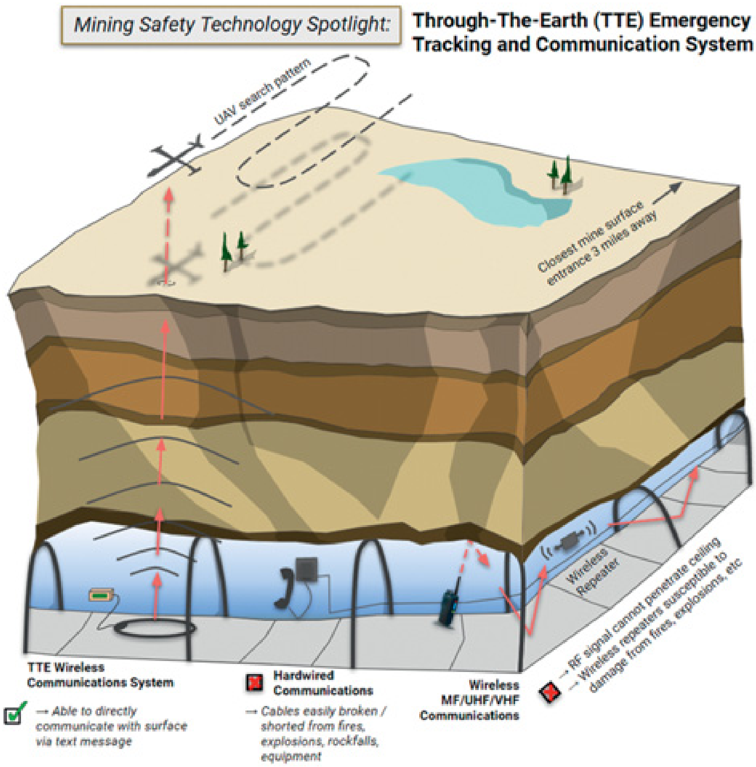

Figure 10.7 Through-the-earth (TTE) emergency tracking and communication system
Source: Author's calculations.

Specifically, we collected the text descriptions from each awarded NIOSH mining safety contract.[22] These descriptions were combined with our dataset of 92 k patent documents from WIPO. Recall that patent documents contain a lot of text describing the invention. Next, we calculated the importance of particular words in each individual document (contract and patent) by using a method called "term frequency, inverse document frequency (TF-IDF)," which is very commonly used for text analysis. This method provides a "content characterization" for each contract and patent based on the text of the document. By looking at the content based on TF-IDF, we calculate the similarity between two documents. The similarity metric we used is called the cosine similarity score.

[22] The data were obtained from the NIOSH-Contract csv file generated from the contract data located at: www.cdc.gov/niosh/mining/researchprogram/contracts/index.html

We posit patents that are more similar to NIOSH contracts (as measured by higher cosine similarity scores) are more likely to be patents directed toward safety technologies as compared those that are less similar (lower cosine similarity scores). To test this hypothesis, we plotted the cosine similarity scores from lowest to highest – least similar to most similar. These histogram plots are constructed using the "kernel density" over the distribution of cosine scores, which we abbreviate as kdensity.

Figure 10.8 shows four kdensity histogram plots. The first and tallest, shown in blue, plots the similarity between NIOSH contracts and all mineral mining patents. It is the tallest of the four plots with most of the scores in the leftmost portion of Figure 10.8. This means most mineral mining patents have a low similarity to the NIOSH mining and safety & health contracts (the mean score is 0.0037). Similar plots are shown for safety patents (brown curve), TTE communications patents (green curve) and refuge chamber patents (orange curve). The overall takeaway is that safety-related mineral mining patents are more similar to NIOSH contracts because the brown curve is to the right of the blue mineral

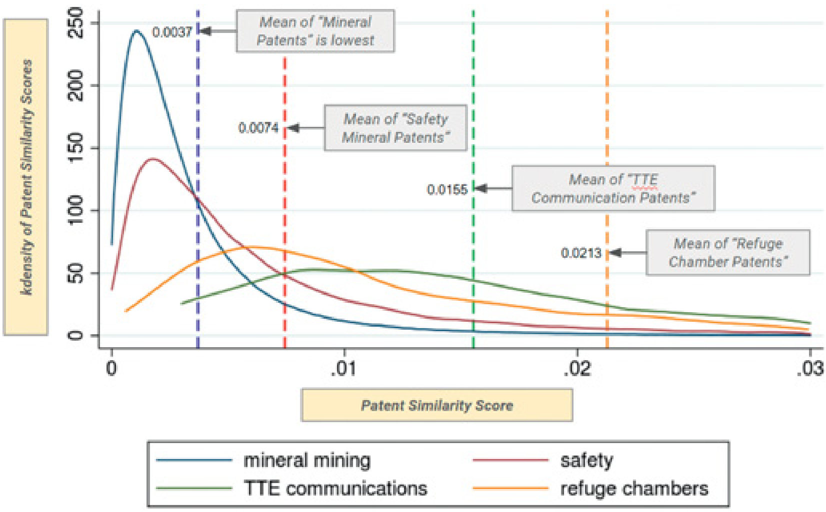

Figure 10.8 Distributions of similarity scores for NIOSH granted patents in four mutually exclusive groups (mineral mining, safety-related mineral mining, TTE communications and refuge chambers)
Source: Author's calculations.

mining patents curve. This substantiates our prediction that patents with higher cosine similarity scores vis-à-vis the NIOSH contracts are more likely to be patents directed toward safety technologies. We also show that both TTE communication and refuge chamber patents have higher cosine similarity suggesting that they are more likely to be safety related as well as within the scope of the MINER Act.

10.5.4 Regression Analysis

Unlike the previous forms of evidence presented, regression analysis allows us to identify a systematic relationship between the passage of the 2006 MINER Act and health outcomes of mineral miners. Up to this point, our results suggest the MINER Act spurred technological innovations as measured by safety-related patents. But the Act also imposed a number of non-technological requirements on mine owners, such as data collection, training and local emergency coordination. Did the technological and nontechnological aspects of the MINER Act have economically impactful results? Specifically, did the MINER Act result in fewer injuries at mines or fewer workdays lost?

To evaluate this question we constructed a mine-level longitudinal dataset covering the years 1995–2014. This means our data contains repeated observations on individual mines over time. The data, which come from the public records of the Mine Safety and Health Administration (MSHA), contain various injury and work loss records for each US mine for various years. For our analysis, we restricted attention to about 2,200 underground mines. The key variables used in the regression models are:

(1) Health Outcome "injuries": any injury of a miner at the worksite (MSHA injury codes 1–6)
(2) Health Outcome "lost work": number of miners with lost workdays (worker production codes 1–4)
(3) MINER Act: an indicator that captures the effect after the passage of the 2006 MINER Act

The results of the regression model are shown in Table 10.1.[23] The regression model holds constant any mine-specific characteristics that

[23] The regression model is as follows: $Injuries_{it} = \beta_0 + \beta_1 MINERAct_t + \gamma_t + \mu_i + e_{it}$. The regression model was estimated using STATA's xtpoisson command controlling for unobserved mine-specific effects and using robust standard errors.

Table 10.1 *MINER Act on health outcomes, 1995–2014*

	Injuries		Lost Work	
	Coef.	Std. Err.	Coef.	Std. Err.
MINER Act	−0.709***	(0.079)	−0.705***	(0.095)
Year dummy variables	YES		YES	
Observations	16,463		15,830	

Robust standard errors. Significance: * p < 0.1, ** p < 0.05, *** p < 0.01.
Source: The mining injury data for the years 2000–14 was downloaded from https://arlweb.msha.gov/OpenGovernmentData/OGIMSHA.asp

are time constant. These characteristics include, for instance, the type of mine (e.g. coal, metal or nonmetal mine), location, different levels of state regulation, management policies and so forth. The regression model also accounts for time-changing factors that affect health outcomes of all mines using year dummy variables (e.g. medical advances that are available to all US miners that may reduce injuries or time away from work for all mines). The key variable, MINER Act, captures the influence of the MINER Act on injury and lost work. In Table 10.1, the variable MINER Act has a negative and highly statistically significant coefficient indicating a systematic decline in injuries and lost workdays following the passage of the MINER Act in 2006. The coefficient sizes are quite similar and suggest about a 51 percent (1-exp(−0.709)) decline in injuries and lost workdays.

10.6 Conclusion

This chapter explores the level and trends in technological innovation for the US mineral mining industry using patent data. Within this industry, we investigate the impact of the **M**ine **I**mprovement and **N**ew **E**mergency **R**esponse (MINER) Act of 2006 on US patenting, innovation and economic outcomes. The analysis offers a general approach for creating curated patent collections related to particular themes or industries (called patent landscaping) and applies it to US mineral mining. Our approach augments the traditional approach used by WIPO to identify global mineral mining patents, which uses patent classifications and Boolean queries with keywords, with machine learning (see Toole et al. (2019) for a technical description). This approach identified 45,572 US mineral mining patents and a subset of 1,311 mine safety-related patents out of an initial set of 91,818.

Our investigation examines four types of empirical evidence on the impacts of the MINER Act. The first type of evidence graphically displays the level and trends in US mineral mining patents as well as the subset of those related to mine safety. Visual inspection shows the growth in safety-related patents is much greater than the growth overall mineral mining patents following the MINER Act. Next we examine two case studies: refuge chambers and "through-the-earth" wireless communications. Both of these illustrate useful technologies that emerged following the MINER Act. Our third form of evidence uses the similarity in the text contained in NIOSH contracts and text contained in US granted patents to assess if patents were more similar to mining safety following the MINER Act. The data analysis supports this conjecture. Finally, we offer regression evidence based on longitudinal data from US underground mines between 1995 and 2014. That analysis finds that the MINER Act is associated with a 51 percent decrease in both injuries and lost workdays. We conclude that the 2006 MINER Act improved technological innovation related to mine safety and resulted in improvements in health outcomes among US miners.

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