A Light in the Darkness: U.S. Mine Lamp Patents —Shedding Light on Innovation

By Paul J. Bartos

The first two articles in this series looked at the detailed technological history of U.S. mine lamps. In this last article we will take a broader view, turning to the specific trends in the patent history of these fascinating artifacts to shed light on some of the associated implications about technological advance and innovation in general, as well as on the nature of technological adaptation within the mining industry during the late nineteenth and early twentieth centuries.

Since the pioneering work of economist Jacob Schmookler in the mid-1960s, economic historians have used patent records as a way to quantify technological innovation and trace the patterns of inventive activity. This article challenges some of the underlying assumptions in this approach and expands upon Schmookler's analysis.[1]

The rapid technological progress and prosperity enjoyed by the United States from the mid nineteenth century into early twentieth century has been attributed in part to its distinctive and broad-based patenting system. The Patent Act of 1836 significantly strengthened the property rights associated with a patent. This, combined with a relatively cheap and accessible filing system, led to an outburst of patent activity from a wide range of the population.[2]

By the 1840s a well-developed commercial market for patent rights already existed, and agencies of the day strongly encouraged patenting.[3] The U.S. Patent Office regularly published descriptions of the new patents granted, and it maintained offices throughout the country where patent models could be displayed and examined. Technical magazines, often with extensive advertisements listing patent agents or the marketing of patents, arrived in the mid 1840s.[4]

People from all walks of life became interested in and received patents. Only later, in the early part of the twentieth century, did the strong association of inventors and corporations seen in modern research and development take hold.[5] Prior to that, patenting was much more individualistic; the later part of nineteenth century has been called "the golden age of the individual inventors."[6]

But what is so special about mine lamps and their patents per se? They are utilitarian, technologically simple devices and their history and advances can be easily understood. They cover a broad sweep of history, on the order of 160 years, from 1850 to the present. More importantly, they have an extremely thorough patent history by virtue of being collectors' items.

Collectors have diligently searched patent records and published their results in order to use patents to identify the various models extant.[7] This sort of detail in the patent record is not typically available for most inventions. As a result, one can trace the twists and turns in mine lamp design, from first initiation into the marketplace through to technological obsolescence. Thus, we can examine in detail actual patenting history and see how it compares to what has been predicted in economic theory.

What the patent history for a given type of mine lamp typically shows is a general increase in the number of patents granted on an annual basis through time, reaching a peak, and then rapidly declining. Of critical significance, extensive patenting continues to occur in all cases for considerable time after the entrance of a disruptive, superior technology—a better mine lamp type—into the marketplace.

Further, mine lamp patent history clearly demonstrates that the vast majority of patents for a given lamp type occur well after the major innovations had been discovered and the fundamental design established. The actual percentage of mine lamp patents containing significant technological innovation turns out to be a very small subset—1 to 2 percent of the total patents. The overwhelming driver in late nineteenth- through early twentieth-century mine lamp patents was the attempt to acquire profits, mostly through small-scale modifications of pre-existing designs. Creating significant original advances in the state of the technological art appears to have been, at best, a secondary consideration.

We will focus on the patent history of four of the U.S. mine lamp types: candlesticks, spout oil wick lamps, safety lamps, and carbide lamps. Covered oil lamps and electric cap lamps have been excluded because much of the usage period of covered oil lamps predates the Patent Act of 1836, and the patent record of electric cap lamps is, comparatively, far less well understood.

Patent Analysis and Cumulative Progress Curves

In this section, we will use mine lamp patents in an attempt to quantify the duration of and interest in a given type of mine lamp, as well as the degree and kind of innovation responsible for various kinds of mine lamps. In contrast to most other inventions, virtually every U.S. patent relating to a mine light is known. The exception is electric battery lamps; these are not collectors' items, as they have remained essentially the same visually for most of their existence.

Candlesticks

Figure 1, documenting the rate of patenting over the forty-five-year period of candlestick development, shows only a modest development of candlestick holders in the first fifteen years, 1872-88, followed by increased but irregular patenting, averaging nearly three patents per year, for the next twenty-one years, 1889-1915. The last years, 1916-17, featured a sharp decline in patenting.[8]

Figure 2 features a newly designed curve, termed a cumulative progress curve. This curve visually represents the significant technological

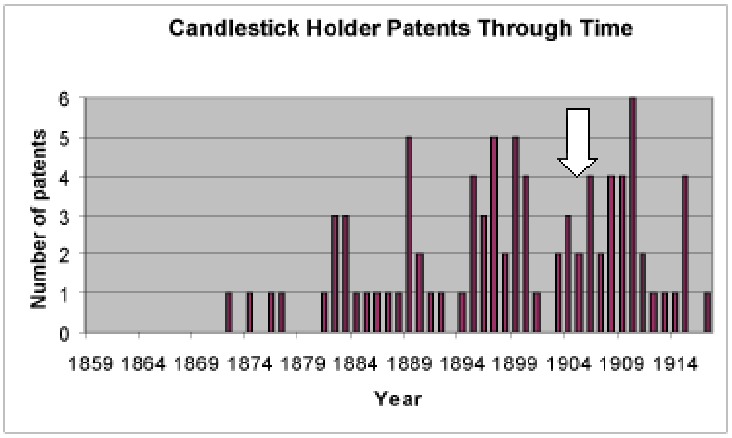


Figure 1: The bold arrow represents the period of initial mass-market acceptance of the carbide lamp, which replaced the mine candle and candlestick.

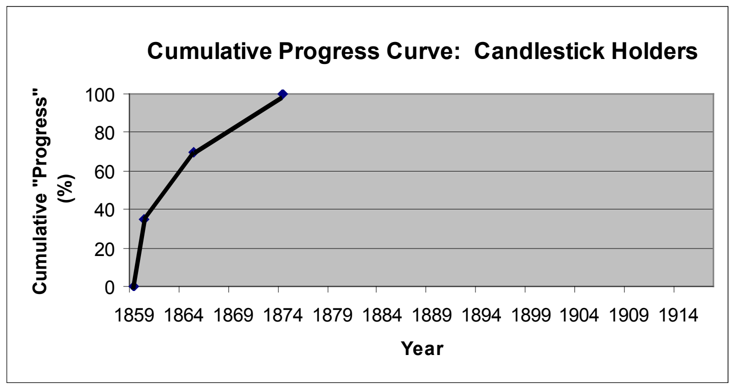


Figure 2

advances of a given product through time. Important technological milestones of a given invention are assigned a percentage of the total perceived technological advance; these cumulatively sum up to 100 percent.

These milestones and their relative worth were not arbitrarily assigned; a strong effort was made to gauge each advance in the context of the invention as a whole. In many cases the specific technological advances are agreed upon by workers in the field, however, the respective percentages were estimated by the author.

In the case of a candlestick, the important advances are viewed as the holder itself, invented in 1860, the handle in 1865, and the hook used to hang the candle from a hat, originated in 1874. Other patents are for only minor refinements on the basic candlestick design. The wide variety seen and lack of building upon these variations in later models further suggest that these other patents were for incidental features not central to the principal invention. There does not appear to have been any significant advance in the candlestick once the basic design had been worked out in 1874.

Comparing Figures 1 and 2 shows some surprising differences. First, there is actually a lag between when the innovation originated, as determined from historical records, and when the first patents were granted. In the case of candlesticks, this lag was on the order of a dozen years: from 1860, when the first evidence of mining candlesticks can be documented, to 1872, the date of the first patent. Likewise there appears to be a lag at the end of the patent histogram. Candles began to be supplanted by carbide and electric lamps starting in about 1905, and by 1915 candles as a mine light were clearly on their way out. Nonetheless, patenting of candlestick holders continued until 1917, although the total number of patents steeply declined.

The other major point revealed when comparing the two curves is that the relative amount of "progress" is not reflected by the patent activity. In the case of candlestick holders, the major advances occurred early on. In fact, the major innovations appear to have preceded the patenting.

Spout Oil Wick Lamps

The spout oil wick lamp is highly similar to the candlestick, in that it is a straightforward, relatively simple invention, but with a large number of patents over an extended period of time—fifty-seven years. As with candlesticks, there was an extended lag time between the introduction of the invention, in 1850, and the first U.S. patent, in 1858. After that, minimal patent activity occurred for at least the following decade. The patent histogram in Figure 3 reflects two main pulses of patent activity, 1875-85 and 1894-1913, with a one year spike in 1890. Of particular note is the abrupt termination of patents for oil wick lamps in 1915.

The cumulative progress diagram for spout lamps, Figure 4, differs somewhat from that of candlesticks. Two major innovations occurred in the spout lamp. One was the idea of the spout lamp itself, a portable lamp hanging from the hat which freed the hands. The other was the change to miner's wax, known as Sunshine, which produced a brighter flame with significantly less smoke. The first innovation occurred at the very beginning, in 1850, the second in the middle of the product's life.

The second peak of patent activity coincided with the introduction of Sunshine in about 1900; many of the patents during this period reflect modifications to accommodate this new fuel source. However, as with candlesticks, the majority of patents in oil wick lamps occurred well after the basic design was established. Thus, they represent "tweaks" of the basic design rather than significant technological improvements.

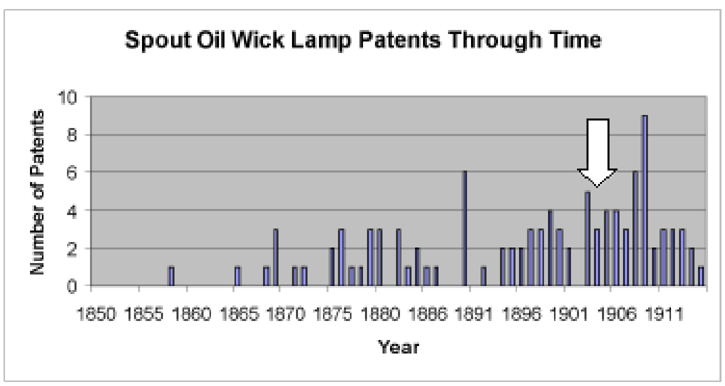


Figure 3: The bold arrow represents the period of initial mass-market acceptance of the carbide lamp, which replaced spout oil wick lamp.

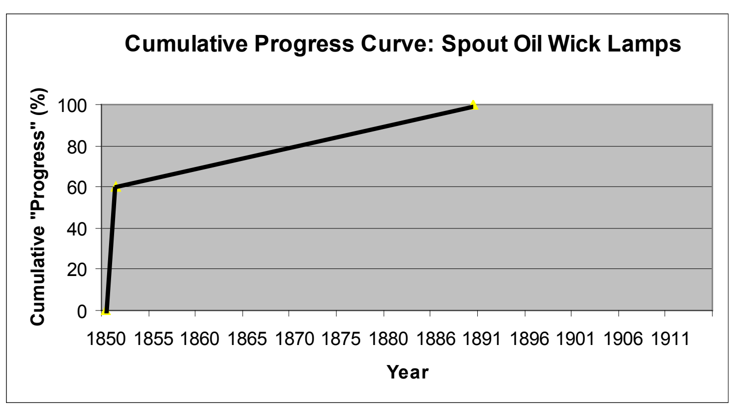


Figure 4

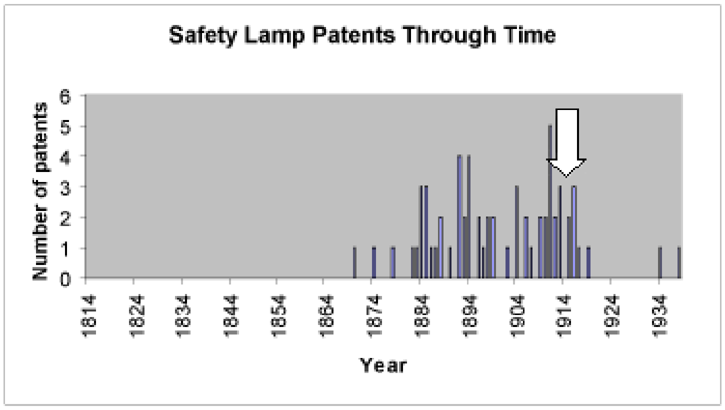
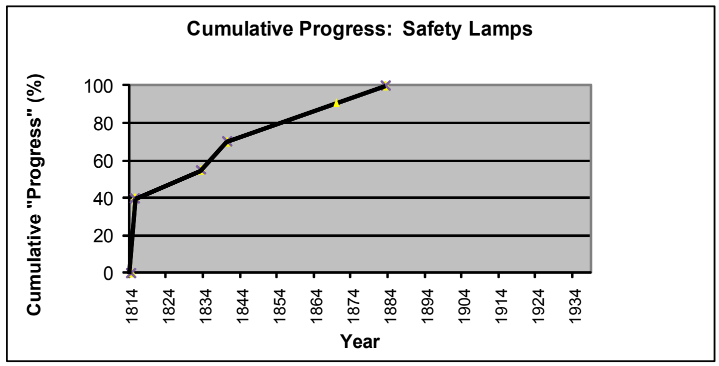


Figure 5: Note that the total patent histogram represents only the total for United States patents; there are many more European patents. The bold arrow represents the period of initial mass market acceptance of the electric cap lamp, which replaced the safety lamp.

Figure 6



Safety Lamps

The U.S. patent history for safety lamps is different than that of the other mine lamps discussed because most of the known innovations, and models, originated overseas. The U.S. patents reflect their introduction into the U.S. market. Sixty-three U.S. patents for safety lamps are known, with many more being registered overseas.

Despite these differences, a look at the yearly patents histogram, Figure 5, reveals some interesting patterns. As with candlestick holders and spout lamps, a significant lag exists between the U.S. introduction of safety lamps, by 1850 at the latest, and the first U.S. patent, in 1870. A thirteen-year period followed before significant patent activity. Starting in 1884 and continuing to 1916, fairly constant patent activity occurred. The peak year was 1911, then the patent rate for safety lamps rapidly decreased to 1919, after which it ceased for fourteen years until several minor patents were issued in the mid 1930s. By that time, the use of safety lamps as a means of illumination had ceased, and the lamps were only used as a gas detection device.

Figure 6, the cumulative progress curve for safety lamps, shows a burst of innovation when the lamp was introduced, followed by a string of significant advances through the first seventy years culminating in the Wolf lamp of 1883. These advances included:

> the use of wire gauze to stop the passage of the flame in the Davy lamp of 1815;
>
> holding an envelope of burnt air above the flame to impede its passage in the Stephens lamp of 1815;
>
> the use of a sealed glass cylinder to enclose the flame and separate it from the outside air, which produced significantly more light in the Clanny lamp of 1815;

complete shielding of the gauze from air currents, with the air supply brought in from below the flame, along with spring-type expansion rings, which also helped to seal the lamp chamber, in the Upton and Roberts lamp of 1833;

a conical-shaped chimney, which aided considerably in areas with high air movement, in the Mueseler lamp of 1840;

multiple cone-shaped gauzes with a protective metal bonnet, which led to significant improvement in safety, in the Marsaut lamp of 1871;

and the use of a high-volatility fuel such as naphtha or benzene, along with independent internal ignition and a magnetic lock, in the Wolf lamp of 1883.

The consensus is that no fundamental improvement in the safety lamp occurred after the Wolf model of 1883, despite another fifty years of patent activity.[9]

Comparing the U.S. patent history of the safety lamp to its cumulative progress curve, in Figures 5 and 6, reveals that the overwhelming majority of patents occurred after the final design was established. In the case of safety lamps, the U.S. patents do not reflect the technological advances, at least not the significant ones.

Carbide Lamps

The carbide lamp fostered 294 known patents over an interval of seventy-nine years.[10] Figure 7 shows two clusters of patent activity: an initial, relatively small, bell-shaped cluster occurs in the interval from 1897 to 1905, and a pronounced cluster starts in 1909 and continues to 1942. This second cluster is decidedly skewed forward, with patent activity showing a marked decrease starting in 1915. This is believed to represent the growing capture of the lamp market by the electric battery lamp. A significant hiatus of thirty years then occurred in carbide lamp patents until the lamps were converted to a hard plastic body. These mid 1970s patents can be considered the last gasp for innovation in carbide lamps.[11]

Most of the significant innovations or improvements in the mining carbide lamp happened in the years from 1913 to 1915. These included:

a flint striker in 1913, so that the lamp could be ignited anywhere without fumbling for matches;

a breeze protector in 1914, because early lamps had the unfortunate tendency to go out with the slightest air movement;

a water-feed valve “dropper” system in 1914, which led directly to a leading lamp model, the Guy’s Dropper, and became the preferred water feed mechanism;

and cap lamps and hooks in 1915, which freed the hand for working.

Metal reflectors had been introduced in 1905. These produced a spotlight four times brighter than non-reflector models, and represented a significant advance from the glass prism used in early bicycle lamps but clearly impractical in underground conditions.

Comparison of Figures 7 and 8 demonstrates that, as with the other types of mine lamps, patenting in carbide lamps continued for a considerable time, in this case sixty years, after the last significant technological advance in the product. Admittedly this sixty-year interval is distorted by the thirty-year hiatus between 1942 and the last few patents in 1970s.[12] Nonetheless, for an interval of approximately twenty-seven years, the patenting of carbine lamps continued without a significant technological advance, and this period was when the majority of carbide lamp patents occurred.

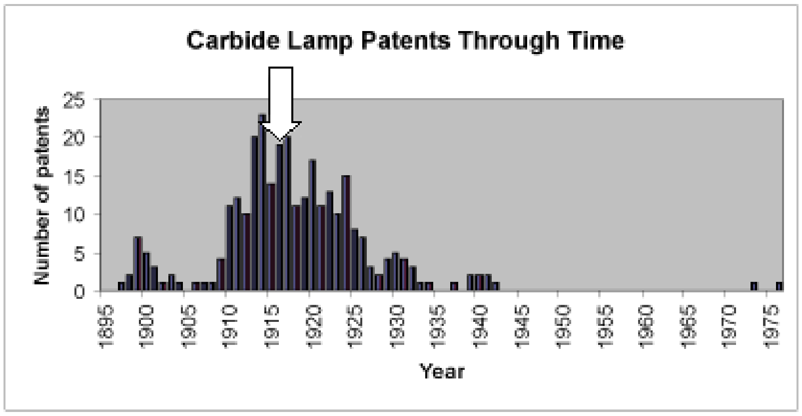
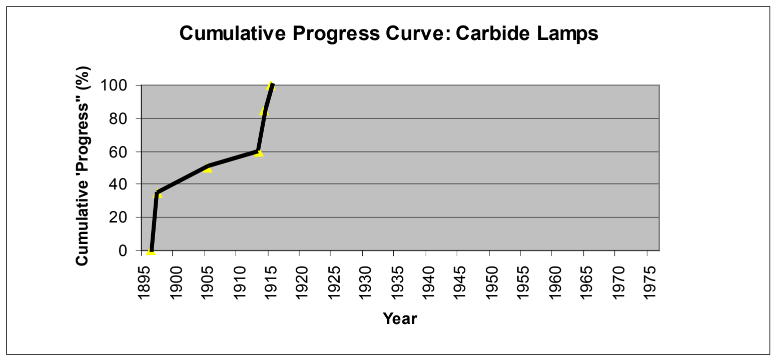


Figure 7: The bold arrow represents the period of initial mass market acceptance of the electric cap lamp, which ultimately replaced the carbide lamp.

Figure 8



Patents and Jacob Schmookler

One sees the same pattern repeated in the patent histories of all the mine lamps: extensive patenting occurring for a considerable time beyond the last significant innovation. Thus the patents clearly reflect other matters besides simply technological advance.

In his pathbreaking book, *Invention and Economic Growth*, Jacob Schmookler used U.S. patent statistics as the main source of evidence to support his thesis that market forces were the fundamental driver upon technological innovation. He felt that patent data could be used to quantify the level of inventiveness in a society as whole, in part based on studies that suggested that a relatively high percentage of patented inventions, approximately half, found commercial application. Using patent renewal data, Mark Schankerman and Ariel Pakes also inferred commercial application rates on the order of 50 percent, although their work has been recently questioned with respect to nineteenth-century English patents.[13]

Other researchers contest this 50-percent estimate. Stacy Jones expressed the opinion that the correct percentage of the commercial application of patents is closer to 10 percent. Historically, the U.S. commissioner of patents estimated in 1869 that only 10 percent of all patents had commercial value. In the case of candlesticks, 38 percent—33 of 87—of all known patents achieved at least some commercial application, with working models known to exist.[14]

The carbide lamp data is far less precise, but a minimal estimate of patents that reached commercial application is 76 of 296, or 26 percent. Unfortunately, neither spout lamp nor safety lamp patent data lend themselves to a similar analysis. Thus, the available mine lamp patent data, if representative of late nineteenth- and early twentieth-century patent data as a whole, suggests that a considerable majority of patents—from 62 to 75 percent—never saw commercial application.

Schmookler used patents as a measure of inventive activity, with each patent representing so many equal units of inventive activity. However, as many authors have observed, all patents are not the same. A small minority represent radical breakthroughs that transform industries or provide innovative products. Other patents represent incremental changes to existing technologies. The vast majority of the patents granted, however, have little or no economic impact. Rather, they appear to be more an attempt to grab market share and profits, without significantly improving the specific invention. This has long been one of the concerns with patent counts—their inability to distinguish between important and trivial technological advances.[15]

This is a significant problem, as the mine lamp patent analysis clearly reveals that the vast majority of patents were for trivial improvements. The candlestick patent data contains only three significant advances out of 87 patents, and only two, or 2.3 percent, were captured in separate patents. Likewise, spout oil lamps had two significant advances out of 110 patents, or 1.8 percent. In carbide lamps, more technologically complex devices, five significant advances occurred in 294 patents, or 1.7 percent. In safety lamps, no significant advances appeared in 63 U.S. patents. If, however, we use significant advances in safety lamps compared to known models, 7 out of 350, it would generate a percentage of 1.1, although the percentage against total patents would be lower.

Overall, mine lamp data suggests that only 1 to 2 percent of all patents actually represent significant technological advances. The remaining patents either never went to market in a commercial application, perhaps 75 percent of the total, or made trivial modifications to existing designs.

Given the populist nature of the Patent Office early in the industrial era, the high percentage of trivial patents registered is perhaps unsurprising. Schmookler's study would suggest that it remains relatively high to the present, albeit at a somewhat lower percentage. The 1 to 2 percent of mine lamp patents embodying significant technological advances in a given lamp type overwhelmingly represent incremental innovation, with the possible exception of the introduction of miners' wax in spout oil wick lamps, a revolutionary advance.

In contrast, the different lamp types themselves, particularly the carbide and electric cap lamps, represent what Anderson and Tuchman term technological discontinuities, defined as "breakthrough innovations that advance by an order of magnitude the technological state-of-the-art which characterizes an industry."[16] By quantifiable measures, such as amount of light provided, or more intangible measures, such as overall safety, carbide and electric cap lamps clearly qualify as technological discontinuities, if not exactly by the order-of-magnitude standard suggested by Anderson and Tuchman.[17]

Various authors have proposed a feedback loop between inventions, the idea being that early inventions will stimulate the creation of later inventions in an ever increasing, upward spiral. Schmookler found no evidence for this in his examination of patent records. The mine lamp patent data supports Schmookler in this regard. There appears to be little or no evidence that prior inventions of mine lamps helped stimulate later varieties.

In fact, the evidence appears to suggest almost the opposite. There appears to have been minimal interchange between coal and metal miners.[18] Each used a different light source, candles or oil lamps, without any apparent diffusion of ideas about lighting techniques. Further, both the carbide and the electric lamp came from outside the industry, and neither appears to have contributed toward the development of the other.

Schmookler also hypothesized that inventive activity is governed by the expected received value for the invention. In this view, inventors are principally inspired to invent when financial rewards are possible; the higher the likelihood of the reward and the greater the possible reward, the greater the number of inventions produced. From this logic, one would expect a larger number of patents to occur once an invention and its markets were clearly established, rather than early on in the innovation's history, when the technology and its market had not been established.

That appears to be the situation with mine lamp patents, where the bulk of patent activity clearly occurs after the technology has been established, and in many cases after it has peaked. The apex of candlestick patenting came in 1912, well after the basic design and practices of the technology were established and its market defined. One could argue that by 1912 the candlestick was not only already obsolete, but clearly so. Spout oil wick lamps and carbide lamps show this same pattern. In each case, the peak of patent activity occurred after a replacement technology had appeared on the scene.

An exception to this pattern lies in safety lamps, where peak patenting occurred just before, rather than after, the introduction of the Edison electric cap lamp in 1915. However, electric cap lamps had already entered the mines in significant numbers with the development of the tungsten filament in 1911, so it could be argued that increased displacement of safety lamps by electric lamps was simply a matter of time. As early as 1914, a report emerged that in mines where electric lamps were being tested, miners preferred them to safety lamps; this did not bode well for the manufacturers of safety lamps.[19]

But the continuation of patent activity with most mine lamps long after an apparently disruptive technology has appeared is striking. All of the mine lamp histograms show a pronounce tail of patent activity for many years after a successive technology had become established. Some of this tail may be explained by the delay in receiving patents. Patent applications may have already been in the system before the disruptive technology was recognized or even present.

But I think that this only constitutes a small portion of the patent tail. In the case of candlestick and the sprout oil wick lamp, patent activity continued for more than a decade after the successful introduction of the carbide lamp. In the case of the carbide lamp, significant patent activity continued for approximately sixty years after the introduction of the electric cap lamp, and for most of that period it was obvious that the electric cap lamp was a superior technology. Even patenting in safety lamps continued for at least twenty years beyond the introduction of the electric cap lamp.

The relatively large number of late patents may mean that a large mature market exists, and not that this market may be potentially transformed. The likelihood of capturing financial reward may be greater in modifying an existing, established technology, rather than in attempting to modify a new "unproven" disruptive technology. This may be so even if the established technology will soon be, or even already is, obsolete.

A general model of patenting for a given invention can be proposed from this data set. Normally, as in Figure 9a on page 42, the rate of patenting for a given invention increases with time up to a peak, where there is an abrupt decline, as the invention is displaced by a new disruptive technology. In this model, the increase in the patent rate reflects the penetration of the invention into the market. With time, more and more inventors would try to expand the product into new or different uses, to capture thereby a share of the associated profits. The rapid decline from peak patent activity would also be expected. Once the market has been disrupted by the new invention, it would become clear that profits were no longer available from the old technology, and inventors would turn their energies elsewhere.

What is notable is the time lag between when a new disruptive technology arises, and is clearly recognized as such, and when peak patent activity occurs. One would predict that, in innovation-driven industries, the time gap between recognition of a superior disruptive technology and peak patent activity on a previous one would be quite small, as in Figure 9a.

In so-called "traditional industries" such as

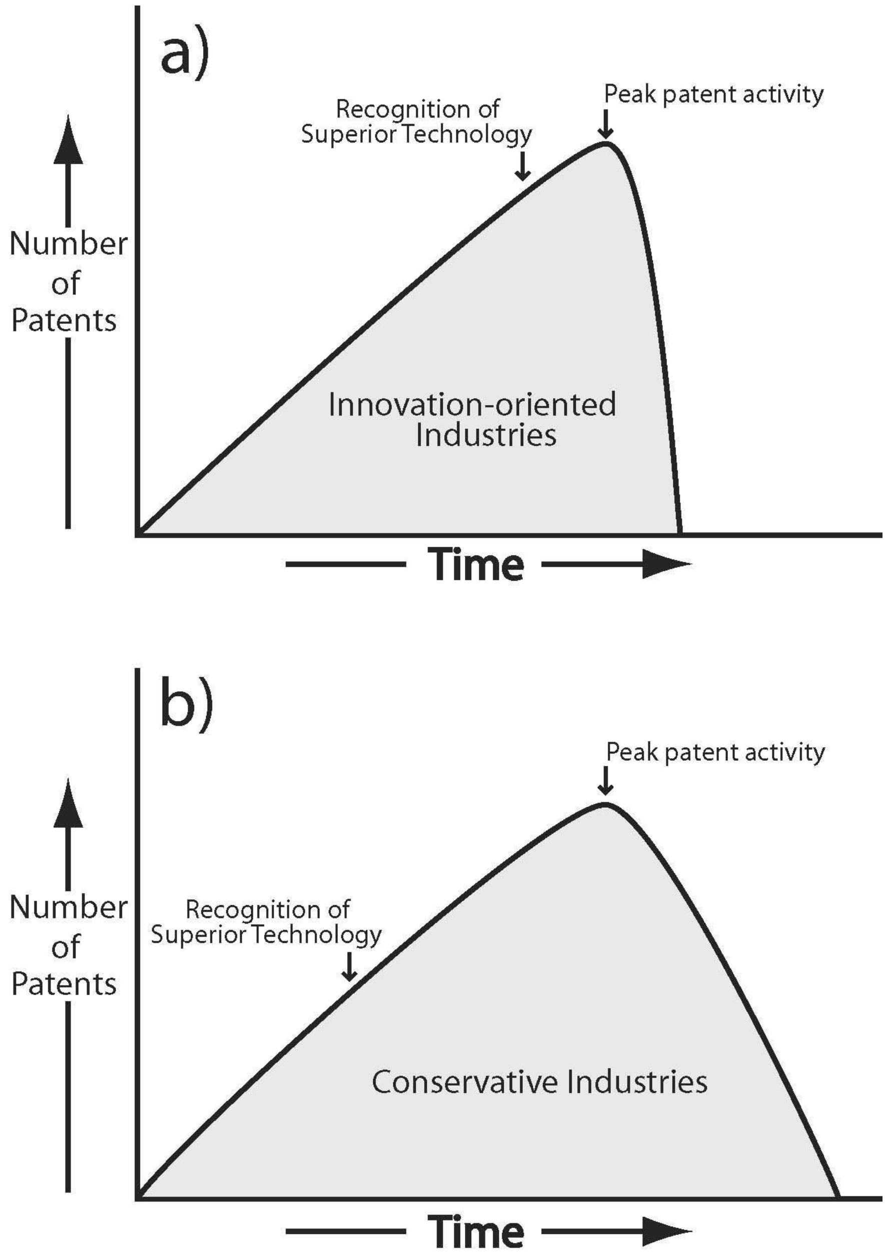


Figure 9: Schematic curve comparing peak patent activity versus recognition of a superior (displacing) technology in innovation-oriented and conservative industries. In this model, all inventions show an increasing patent rate with time, representing the development of the market and individual inventors' attempts to capture some of the profit through modification of the basic design. In an innovation-oriented industry, minimal time occurs between the recognition of a displacing technology and the cessation of inventive patent activity, and the decline from peak patent activity to the end of patenting is steep. In a more traditional industry, such as mining, a longer time between recognition of a disruptive technology and peak patenting allows for continued modification and patenting of the established invention, while the decline in patenting is less precipitous. The B curves were derived from the general shapes of the safety lamp, spout lamp, and candlestick patent curves.

mining, which have slow technological adoption rates, the time gap would be much larger, as in Figure 9b.[20] The decline of patenting in both cases would still be precipitous, although perhaps less so for traditional industries. The difference would be in the time interval from recognition of a superior disruptive technology to cessation of patent activity.

What if a new technology is only superior in certain aspects and not in others? Then one could predict a patent rate curve with a shallow rather than a precipitous decline from the peak patent interval, such as in Figure 10. This appears to correspond to the history of carbide lamps with respect to electric cap lamps.

In many respects, electric cap lamps are superior to carbide lamps, particularly in terms of the quantity of light produced, and in safety—the latter was a critical point in gassy coal mines, much less so in metal mines. However, there was, and is, a distinct cost disadvantage in the electric cap lamps, assuming that electricity for recharging was even available, which was not the case at many mines for many years.

As a result, the carbide lamp held its own in the marketplace against the electric cap lamp for a period of time on the order of forty to fifty years. The gently declining patent curve at the end stages of the carbide lamp's patent history reflects this. In the later years it was probably obvious that electric cap lamps would eventually triumph, so inventive activity in carbide lamps ceased, as companies and inventors turned their energies elsewhere. Indeed, it can be argued that the pro-

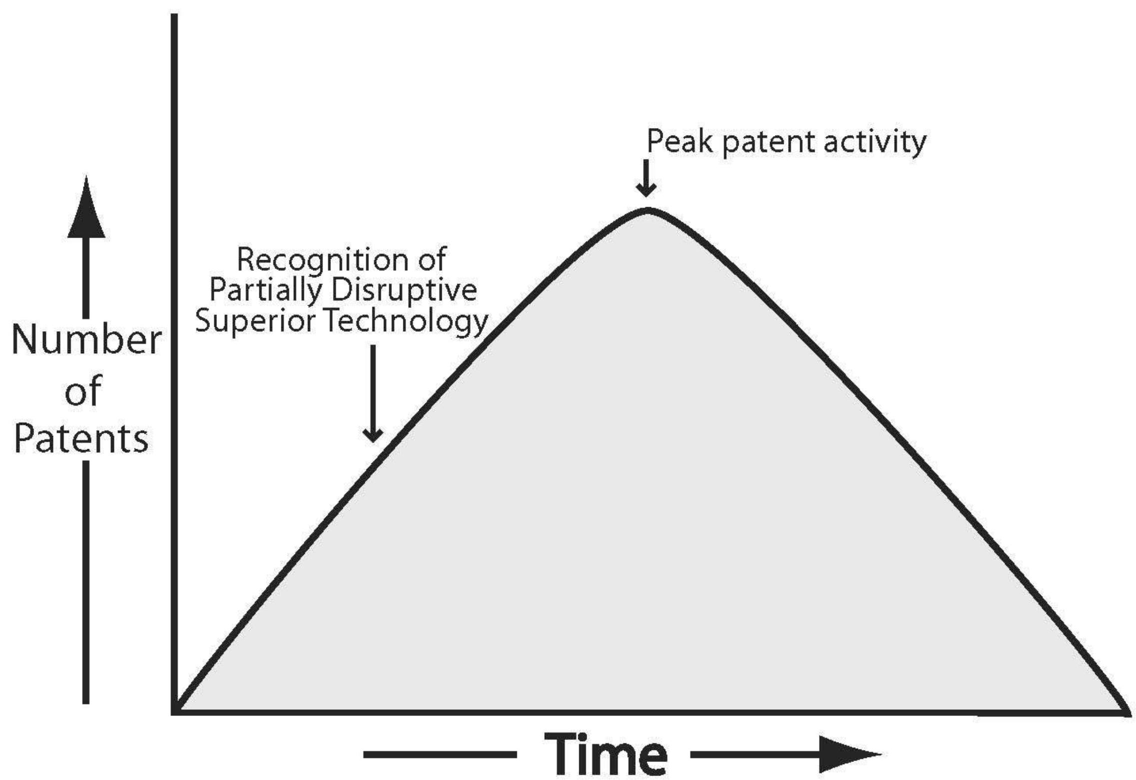


Figure 10: Schematic curve showing patent activity of an invention affected by a partially disruptive technology. This would be for an invention mostly inferior to a new technology, but retaining some advantage. A slow decline from the peak patent rate results, as inventors continue to seek profit from the invention at an ever-decreasing rate. An example is the carbide lamp, which was technologically inferior to the electric cap lamp, but had a lower initial cost.

verbial writing on the wall was apparent well before the actual market totally dried up, as carbide lamp patenting essentially stopped in 1942, but significant sales and usage continued well into the following decade.

It must be emphasized that mine lamp patents comprise an extreme minority of the total patents granted. In the U.S. alone, more than six million patents have been granted since 1790.[21] Using mine lamp patent data as proxy for the U.S. patent universe may well be pushing the data beyond its useful applicability. Nonetheless, the patent patterns seen in this mine lamp study appear consistent, relatively straightforward, and explainable, and follow-up studies on other inventions in other industries seem warranted.

Debate has occurred over which technological stage actually generates the most progress, the initial revolutionary breakthrough or the later accretionary modifications. The consensus view now is that the less spectacular, follow-on innovations may be more important in the aggregate than the major breakthrough innovations.[22] Does the data from mine lighting support this assertion?

With respect to the candlestick, the major innovations occurred early in its development. Despite subsequent modifications and tweaks, the fundamental design appears little changed once it was established in approximately 1878. In spout lamps, a large number of minor, inconsequential modifications occurred, but excluding the significant introduction of Sunshine fuel in 1900, there appears to have been relatively little improvement from the initial design. Likewise, the carbide lamp shows significant improvement in light output, overall ease of use, and efficiency of operations up to about 1915, approximately a quarter of its effective product life. Beyond that point, the lamp does not appear to have significantly advanced.

The stories of safety lamps and electric lamps were different. In safety lamps, three of the most significant design elements appeared in the first year of production, however, significant improvements in illumination, safety, and overall operation continued through a significant portion, sixty-eight years, of its effective life. Beyond that (for almost another century!), relatively little improvement occurred. The electric cap lamp's story appears analogous to that of the safety lamp, with continuing improvement over time, especially in terms of light output and battery weight.

Given that candlesticks and spout oil lamps are technologically simple devices, it may be expected that the bulk of technological innovation would occur in the early stages of their product life. Nonetheless, more technologically sophisticated devices, such as the safety, carbide, and electric cap lamps, also showed extensive early technological advancement. And these three lamp types show subsequent incremental technological advancement as well.

So, the technological tally from this study indicates that with two types—the candlestick and spout oil lamp—the bulk of technological advance occurred in the breakthrough stage. Although all of the mine lamp types saw a significant portion of their technological advance in the initial stage, the other three types—the safety lamp, carbide lamp, and electric cap lamp—experienced the bulk of their technological advance in the accretionary stage. Of these three lamps, however, both the safety and carbide lamps featured an extensive late period in which technological advance, though not necessarily patents, simply stopped, with the data on electric cap lamps being incomplete. The accretionary stage, therefore, cannot be assumed to continue indefinitely—at some point, innovation for a given invention appears to go dormant and its design becomes essentially locked in.

Adoption Lag: An Insight into the Nature of the Mining Industry?

The data presented here documents historically slow adoption rates for new versions of mine lamp technology. Today, much of the public considers the mining industry to be a laggard with respect to innovation and technological adoption.[23]

The productivity data displayed in Figure 11 suggests that this perception of the mining industry is partly correct. It is certainly so when compared to the high tech industries, and is true to a lesser degree with respect to general manufacturing since the end of World War II, when data of this sort was first systematically collected.[24]

Assuming that the adoption rate of mine lamp technology is representative of the overall technological adoption rate of the industry as a whole, this study would suggest that the slow adoption of new technology has been a defining characteristic of the mining industry since at least the 1910s. Within the general time period of this study, the mining industry was also significantly late in adopting modern business organizational structures.[25] And, overall, mining industrialized later than other industries.[26]

Why should this be so? Joel Mokyr, an economic historian specializing in the history of technology, offered the opinion that because mining in general is a complex and interrelated technological system, it will be far less likely to have new revolutionary technological breakthroughs.[27] The idea here is that revolutionary change in one component of technology would have negative consequences in the other interrelated components. Thus, according to Mokyr, there is a sort of technological inertia that dampens change within the industry.

In theory however, this effect should not apply to mine lighting, which is portable and not particularly site-specific beyond the obvious condition of dangerous gases in certain coal mines.

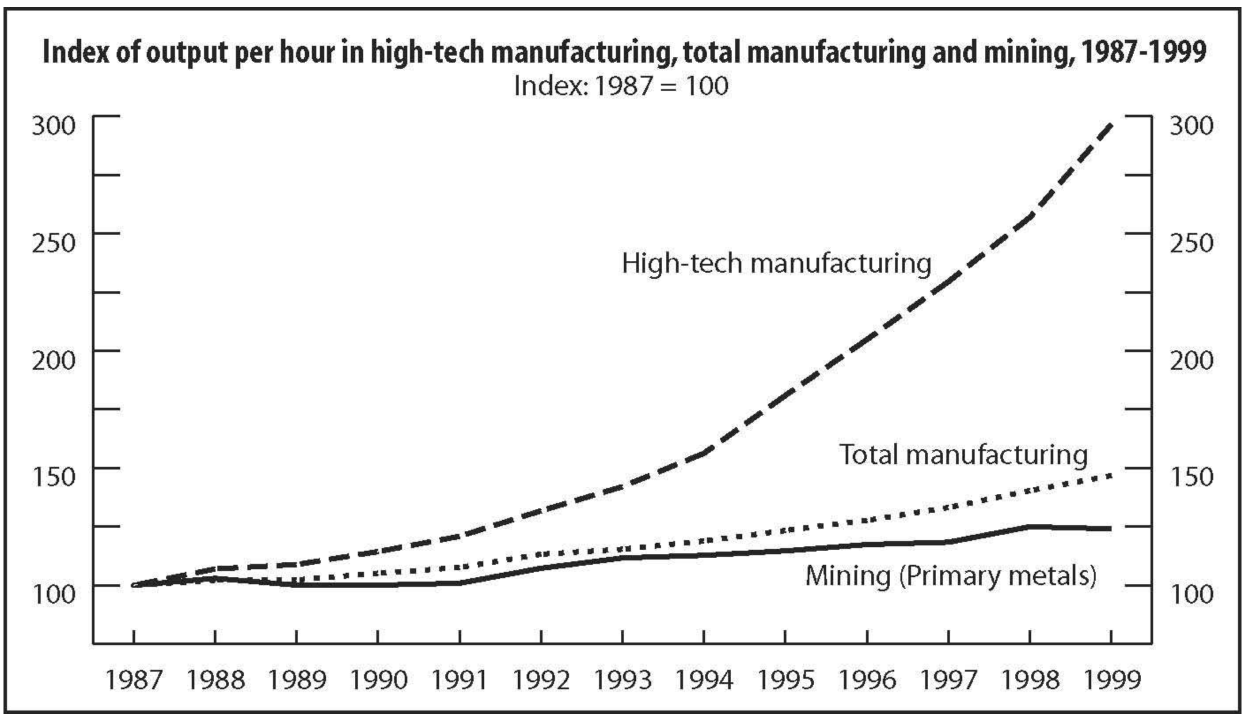


Figure 11: Labor productivity in U.S. primary metal mining, general manufacturing, and high-tech manufacturing, 1987–99. Starting in the 1980s, a divergence on the order of 10 percent occurred between the productivity rates of U.S. metal mining and general manufacturing. That divergence is dwarfed, however, by the productivity gap between mining and the high tech industries. The productivity gaps between mining the general manufacturing and high-tech sectors widened still more after the year 2000. (Data courtesy of C. Kask and E. Seiber ("Productivity Growth in the "High-Tech Manufacturing Industries," Monthly Labor Review *125, no. 3 (2002): 16-31), and the U.S. Department of Labor.)*

Nonetheless, it does seem that there was, and is, an overall climate of resistance to change within the industry.

What accounts for this apparent resistance to change? Possibly it is because mining is fundamentally a commodity business, with an extreme emphasis on controlling and lowering costs. Miners cannot control the price or profitability of the metals they mine; they are at the mercy of the markets. What they can attempt to control is the costs of mining and processing the metal, and, to a far lesser degree, the grade of the metal deposits they mine. However, the single most important factor by far in determining the profitability of the typical metal mine is the metal's price.

As a result, relentless pressure exists to control and lower costs—a mind-set instilled in mining engineers and operators from the very beginning of their careers. This orientation does not, however, typically lend itself to innovation and the embrace of new ideas and technologies.[28]

Discussion

This paper is hardly the first to criticize some of the underlying assumptions of those using patent counts. Science historian Nathan Reingold, in anticipating, then rejecting, Smookler's assumption that patent statistics constitute an index to invention and economic growth, pointed out that "the issuance of a patent simply means that the language of the patent specifications met whatever standards of patentability were in effect at the time."[29]

More recently, the economist Zvi Griliches undertook an extensive review of the possible application of patent counts as economic indicators. In particular, he presented data suggesting that the average commercial value of a given patent, although highly variable and skewed, is increasing in modern-day patents. If so, it may be that the results described in this paper are more applicable to historical patents only.[30]

With the advent of computerized data bases, other scholars, such as Manuel Trajtenberg and Adam Jaffe, have applied sophisticated econometric techniques on modern-day patent citations to trace the flow of technical knowledge from one inventor or organization to another.[31] Still other scholars have used the historic patent record to explore the growth of markets in early industrialization,[32] patterns in inventive activity over time,[33] or the relationship of patenting to market demand.[34]

The patent records remain a treasure trove of data with a myriad of potential applications to economic history. However, this study suggests that a certain amount of caution needs to be exercised in the use of this data, given the apparently high number of patents that were neither commercially successful nor constituted a technological innovation.

The mine lamps cast a certain light on the nature of "new and improved." We are all familiar with various advertisements and commercials touting the latest "new and improved" consumer product, be it toothpaste, bathroom cleanser, or detergent. The question arises: Although the colored cleansing speckles in that detergent may well be new, have they really improved the product? Is that detergent actually better? In the case of late nineteenth- and early twentieth-century mine lamp patents, the answer is quite definitive: no.

The detailed patent history of late nineteenth- and early twentieth-century U.S. mine lamps clearly reveals that the number of patents containing significant revolutionary or incremental technological innovation comprises only a tiny subset of 1 to 2 percent of the patents for a given mine lamp type. Of the remaining 98 to 99 percent of those patents, up to three quarters never made it to market in a commercial application, and the rest were trivial modifications of pre-existing designs.

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Notes:

1. J. Schmookler, *Invention and Economic Growth* (Cambridge: Harvard University Press, 1966). See also: Z. Griliches, "Patent Statistics as Economic Indicators: A Survey," *Journal of Economic Literature* 28 (1990): 1661-1797.
2. B. Z. Khan and K. L. Sokoloff, "The Early Development of Intellectual Property Institutions in the United States," *Journal of Economic Perspectives* 15, no. 3 (2001): 234.
3. B. Z. Khan and K. L. Sokoloff, "'Schemes of Practical Utility': Entrepreneurship and Innovation among 'Great Inventors' in the United States, 1790-1865," *Journal of Economic History* 53 (1993): 289-307.
4. N. R. Lamoreaux and K. L. Sokoloff, "Inventors, Firms and the Market for Technology in the Late-Nineteenth and Early-Twentieth Century United States," in: N. R. Lamoreaux, D. M. G. Raff, and P. Temin (eds.), *Learning by Doing in Markets, Firms, and Countries* (Chicago: University of Chicago Press, 1999).
5. Kahn and Sokoloff, "Early Development of Intellectual Property Institutions," 242, 244. One of the nineteenth century's freelance inventors was Abraham Lincoln, who in 1849 received patent number 6469 for a device to lift steamboats off sandbars.
6. T. P. Hughes, *American Genius: A Century of Invention and Technological Enthusiasm* (New York: Viking Penguin, 1989).
7. See: G. S. Clemmer, *American Miners' Carbide Lamps: A Collector's Guide to American Carbide Mine Lighting* (Tucson, AZ: Westernlore Press, 1987); H. A. Pohs, "Early Underground Mine Lamps: Mine Lighting from Antiquity to Arizona," *Museum Monograph No. 6*, Tucson: Arizona Historical Society, 1974; H. A. Pohs, *The Miner's Flame Light Book* (Denver, CO: Flame Publishing Company, 1995); J. D. Ramsdell and N. S. Wagner, *Patents, Miners' Candlesticks* (Carson City, NV: privately published, 1982); W. W. Wilson, *Miners' Candlestick Patents*, Tucson, AZ: Mineralogical Record, Inc., 1983); W. W. Wilson and T. Brobrink, *A Collector's Guide to Antique Miners' Candlesticks* (Tucson, AZ: Mineralogical Record, Inc. 1984).
8. Patent information and totals in this and subsequent sections reflect described patents in the published literature. Collectors are continually searching for and occasionally finding additional patents, which may change the totals slightly.
9. G. E. Bayles, "The History of Mine Lighting, Part 2," *Mechanization* 21, no. 1 (1957): 75; Pohs, "Early Underground Mine Lamps," 65.
10. Pohs, *Miner's Flame Light Book*, 735-46.
11. Dating early carbide mine lamp patents can be a bit tricky because the carbide lamp was first designed as a general purpose illuminant, originally used on bicycles, and then migrated into the mining sphere. The first carbide lamp generally considered suitable for mining purposes was Baldwin's 1900 lamp, and the testing of carbide lamps within the mines dates from that time. By 1905, Baldwin lamps were used in both coal and metal mines, and the metal reflector, a key component for underground work, dates from that time. The first carbide lamp marketed and advertised specifically for mining purposes was the 1906 Baldwin Pit Lamp. Mass acceptance appears to have followed quickly. In 1914, the Baldwin Miner's Lighting Bug Lamp was advertised as "still satisfactory after eight years of service without any radical changes"—a less-than-inspiring advertising slogan, but one that emphasized the technological continuity and lack of significant modification of that particular lamp, one of the leading models of the time. (Clemmer, *American Miners' Carbide Lamps*, 16-7, 64.)
12. By then, the principal use of carbide lamps in the United States was in outdoor recreations such as caving, hunting, and camping, rather than in mines.
13. M. Schankerman and A. Pakes, "Estimates of the Value of Patent Rights in European Countries during the Post-1950 Period," *Journal of Economics* 96, no. 384 (1986): 1052-76; C. MacLeod, J. Tann, J. Andrew, and J. Stein, "Evaluating Inventive Activity: The Cost of Nineteenth-Century UK Patents and the Fallibility of Renewal Data," *Economic History Review* 56, no. 3 (2004): 537-62.
14. S. V. Jones, *The Patent Office* (New York: Praeger, 1971); Institute of Electrical and Electronics Engineers, *Patents and Patenting* (New York: John Wiley and Sons, 1982).

15. Khan and Sokoloff, "'Schemes of Practical Utility,'" 289-307; and "Early Development of Intellectual Property Institutions," 240.
16. P. Anderson and M. L. Tushman, "Managing through Cycles of Technological Change," *Research–Technology Management Journal* (May-June, 1991): 26-31.
17. See: P. J. Bartos, "A Light in the Darkness: U.S. Mine Lamps, The Early Years—Candlesticks, Oil Lamps and Safety Lamps," *Mining History Journal* 16 (2009): 52, Tab. 1. The amount of light provided was two to six candlepower by early carbide lamps, ten to seven candles by post-1914 carbide lamps, one to three candles by early electric cap lamps, and greater than seventy candles for post-1931 electric cap lamps. This compared to about 0.7 to 1 candlepower for spout oil wick lamps, safety lamps, and candles.
18. Bartos, "A Light in the Darkness . . . the Early Years," 60.
19. H. H. Clark, "Permissible Electric Lamps for Miners," *U.S. Bureau of Mines Technical Paper 75*, 1914, 5. For discussion of the evolution of the electric lamp underground see: P. J. Bartos, "A Light in the Darkness: Modern U.S. Mine Lamps—Carbide and Electric Lamps," *Mining History Journal* 17 (2010): 94.
20. For a discussion of mining's slow adoption of technology, see: P. J. Bartos, "Is Mining a High Tech Industry?: Investigations into Innovation and Productivity Advance," *Resources Policy* 32 (2007): 149-58.
21. A. Jaffe and M. Trajtenberg, *Patents, Citations, Innovations: A Window on the Knowledge Economy* (Cambridge, MA: MIT Press, 2002), 2.
22. J. L. Enos, "Invention and Innovation in the Petroleum Refining Industry," in: *The Rate and Direction of Inventive Activity: Economic and Social Factors: A Conference of the Universities-National Bureau Committee for Economic Research and the Committee on Economic Growth of the Social Science Research Council* (Princeton, NJ: Princeton University Press, 1962), 299-321; S. Hollander, *The Sources of Increased Efficiency: A Study of du Pont Rayon Plants* (Cambridge, MA: M.I.T. Press, 1962); P. Anderson and M. L. Tushman, "Managing through Cycles of Technological Change."
23. P. J. Bartos, "Innovation in the Mining Industry through Time" (Ph.D. diss., Colorado School of Mines, 2006).
24. Bartos, "Is Mining a High Tech Industry?"; P. J. Bartos, "How Does the Mining Industry Rate?: A Look at Innovation and Productivity Advance," [*sic*] *SEG Newsletter* n. 75 (2008): 1, 8-12.
25. A. D. Chandler, Jr., *The Visible Hand: The Managerial Revolution in American Business* (Cambridge, MA: Belknap Press, 1977), 329-30.
26. K. H. Ochs, "The Rise of American Mining Engineers: A Case Study of the Colorado School of Mines," *Technology and Culture* 33, no. 2 (1992): 278-301.
27. J. Mokyr, *The Lever of Riches: Technological Creativity and Economic Progress* (New York: Oxford University Press, 1971), 296.
28. Another factor to consider in the innate conservatism of the mining industry, compared to high tech, is safety. Mining is a dangerous profession, particularly underground, with an understandable reluctance on the part of miners to change over to unproven new products and techniques. The expression "safety regulations are written in blood" exists for a reason, and the same axiom might apply to technologies and practices. Doing the same things in the same ways every time provides greater security, and new products or techniques may challenge that security. These factors could well account for some of the industry's relative resistance to change.
29. N. Reingold, "U.S. Patent Office Records as Sources for the History of Invention and Technological Property," *Technology and Culture* 1 (1960): 156-7.
30. Griliches, "Patent Statistics as Economic Indicators," 1661-1797.
31. Jaffe and Trajtenberg, *Patents, Citations, Innovations*.
32. K. L. Sokoloff, "Inventive Activity in Early Industrial America: Evidence from Patent Records, 1790-1846," *Journal of Economic History* 48, no. 4 (1988): 813-50; K. L. Sokoloff and B. Zorina Khan, "The Democratization of Invention during Early Industrialization: Evidence from the United States, 1790-1846," *Journal of Economic History* 50, no. 2 (1990): 363-78.
33. R. C. Post, "'Liberalizers' versus 'Scientific Men' in the Antebellum Patent Office," *Technology and Culture* 17, no. 1 (1976): 24-54.
34. Khan and Sokoloff, "'Schemes of Practical Utility,'" 289-307.