Property in Land and Other Resources

Edited by Daniel H. Cole and Elinor Ostrom

Foreword by Douglass C. North

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Daniel H. Cole *and* Elinor Ostrom

LINCOLN INSTITUTE
OF LAND POLICY
CAMBRIDGE, MASSACHUSETTS

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Library of Congress Cataloging-in-Publication Data

Property in land and other resources / edited by Daniel H. Cole and Elinor Ostrom.
p. cm.
Includes index.
ISBN 978-1-55844-221-4
1. Right of property. 2. Real property. 3. Natural resources. I. Cole, Daniel H. II. Ostrom, Elinor.
HB701.P737 2012
333.3—dc23 2011029993

Designed by Westchester Book Services

Composed in Minion Pro by Westchester Book Services in Danbury, Connecticut.
Printed and bound by Puritan Press Inc., in Hollis, New Hampshire.

♻ The paper is Rolland Enviro100, an acid-free, 100 percent PCW recycled sheet.

MANUFACTURED IN THE UNITED STATES OF AMERICA

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KAREN CLAY AND GAVIN WRIGHT

This chapter argues that the discovery of gold in California and a federal policy that gave all the rents in minerals on federal land to private parties led to two important and closely related outcomes. The first outcome was the development of a private-order property rights regime in the gold-mining region, key elements of which would later be adopted as federal law. This regime, often considered a canonical example of the emergence of private-order property rights, protected the rights of active users of gold-bearing land.[1] As Umbeck (1981) documented, the rights and responsibilities of miners in a particular area were memorialized in a mining-district code that defined who could hold rights, what the rights were, and procedures for transferring rights. These codes and associated norms were successful at controlling violence and so allowed miners to focus the bulk of their energies on mining.

Mining-district codes also included provisions for the reallocation of rights of inactive users through claim jumping. Clay and Wright (2005) argue that mining claims were not secure property rights as that concept is conventionally understood. This insecurity was in a sense built into the system, in that district codes gave considerable attention to the rights of claim jumpers, individuals who took over a claim deemed to be abandoned. Far from being a violation, claim jumping brought productive land into use and was the most common method of acquiring a claim.[2] Thus, codes both protected production on existing claims and regulated access to mining sites in a competitive race for high-value deposits.

The development of property rights in mineral land and the allocation of rents to private parties led to large-scale activity in mining. This scale fostered the second outcome, the development of a knowledge economy in minerals. U.S. mining during the nineteenth century displayed many of the features now associated with a knowledge economy, including synergies between higher education and industry, federal support for scientific research and infrastructure, diffusion of codified forms of useful knowledge, and economic progress based on extension of the knowledge

[1] See, for example, Umbeck's (1981) pioneering work, as well as Barzel (1997); Ellickson (1991); and Shavell (2004). Umbeck is also cited favorably in American economic history textbooks, for example, Walton and Rockoff (1998).

[2] The authors owe this insight to Andrea McDowell.

frontier. For nonrenewable resources like minerals, a prima facie analysis would suggest that open access would generate wasteful dissipation of rents through undue haste, excessive investment of labor and capital, and premature depletion as competitors race to extract dwindling resources ahead of their rivals. Some parts of the history conform to this scenario, but the larger picture is that of dynamic, innovative advances in resource discovery, extraction, and processing that together created the world's leading national mining sector.

Property Rights in the Gold Rush

The Rush

On 24 January 1848, James Marshall discovered gold at John Sutter's mill in Coloma in what would later be El Dorado County. Information about the discovery of gold took most of 1848 to spread, however. In March the *Californian*, a San Francisco newspaper, printed a story about the discovery of gold, but the streets of San Francisco did not immediately empty. In May Sam Brannan arrived in San Francisco and began to advertise the arrival of the gold rush. A store owner at Sutter's Fort and the publisher of the *California Star*, Brannan stood to gain from any increase in gold-mining activity. In June an estimated four thousand to five thousand miners were at work in the gold district, a very large share of the adult male population in California. By the end of July, two thousand copies of a special edition of the *California Star* had reached Missouri. In August the *New York Herald* printed a story on the discovery of gold. And in December President Polk confirmed the rumors in his address to Congress.

By late 1848 the whole American nation and many foreign countries knew about the California gold rush. Many headed for California in the spring of 1849, either overland or by ship. Estimates suggest that between five thousand and six thousand wagons left Missouri in the spring of 1849. Others took overland routes that began farther south or even in Mexico. For the period 1848 to 1850, lower-bound estimates of overland migration are more than 101,000.[3] Ships had also begun to leave New York and other cities on the Atlantic seaboard for California. The ships either took the long route around Cape Horn to California or left the passengers in Panama. In the latter case, the passengers then traveled across Panama and took a second ship from Panama to San Francisco. For the period 1849 to 1850, arrivals by sea are conservatively estimated at 75,462.

Clay and Jones (2008) show that by the end of 1850, 1.9 percent of native-born men aged 20 to 40 were already in California. Because of undercounting and the loss of census records for some counties, this number was probably closer to 3.1 percent. Only military-related migrations would induce a more rapid migration of young men in a comparably short period of time.

[3] Estimates of overland migration and passenger arrivals by sea are summarized in D. M. Wright (1940). A substantially higher figure for 1849 immigration is presented in the *State Register and Book of Facts* (1857). The fact that total arrivals were as much as 50 percent larger than the recorded 1852 non-Indian population of 223,856 suggests that many newcomers had already left.

Mining in a Legal Vacuum

Most national mining systems descend from the tradition that valuable minerals belong to the lord or ruler, who grants use rights as "concessions" in exchange for a share of the revenue. The U.S. government was by no means immune to the attractions of mineral revenues. Continuing colonial-era practice, the Land Ordinance of 1785 reserved for the federal government "one third part of all gold, silver, lead and copper mines, to be sold or otherwise disposed of, as Congress shall direct." Although minerals were not mentioned in the land laws of 1796, 1800, and 1804, Congress did act in 1807 to reserve lead mines in the Indiana Territory. Between 1824 and 1846, the government maintained a leasing system in the Galena District of Illinois, Iowa, and Wisconsin: miners were given exclusive permits to work certain areas and in return were required to bring their ore to one of the officially licensed smelters, who were required to pay a 10 percent royalty. The plan worked reasonably well in the 1820s, when production and federal revenue both grew. It fell apart in the 1830s, however, when nonpayment and noncompliance became widespread. Authorities in Washington lacked enforcement power, even over their own agents, who abetted evasion by smelters and fraudulently sold valuable mineral lands at minimum farmland prices, almost surely with side payments for personal profit.

The mining expansion of 1836 to 1840 generated no government revenues. British observer Frederick Maryatt commented: "How weak must that government be when it is compelled to submit to such a gross violation of all justice" (quoted in J. E. Wright 1966, 47). During the 1840s, the Ordnance Department attempted "reluctantly and halfheartedly" to reinstitute a leasing system for Michigan copper lands, but the results were no more successful, and the efforts were abandoned in 1846 (Mayer and Riley 1985; J. E. Wright 1966, 72).

By the eve of the California gold rush, the federal government had abolished all administrative apparatus and enforcement machinery pertaining to minerals in the public domain. Moreover, Mexican law was not in effect. On 12 February 1848, evidently still without knowledge of the gold strike, Colonel Richard B. Mason, commander of the American military forces, declared: "From and after this date, the Mexican laws and customs now prevailing in California, relative to the denouncement of mines, *are hereby abolished*" (quoted in Yale [1867], 17). Mason's intention was to protect private property in land from preemption for minerals under Mexican law. The effect, however, was to thwart any attempt to develop private mineral titles using Mexican rules. Having neither authorization nor capacity, Mason put no new system in place and declined to evict trespassers from the public domain. Thus, thousands of fortune seekers raced one another westward in the belief that gold was free for the taking, subject neither to government control nor to private land ownership.

Once the rush began in 1849, Congress considered many proposals to generate federal revenue from the gold fields, including mining licenses, auctions, leases, and sale of small mining tracts at farmland prices. The prospects for effective enforcement, however, were even more daunting at a distance of three thousand miles than they had been in the Midwest. After several early measures failed to gain support, both executive and legislative branches acquiesced in a policy of nonintervention.

Inaction was further supported by the arrival of political representatives from the new western states, who opposed any measures that might constrain the extension of the mining frontier and drain revenue from the region. As a result, no federal mining legislation was passed until 1866 (Ellison 1926).

Mining-District Codes

For some months, gold mining went forward under truly wide-open conditions, subject to no regulation of any kind.[4] This state of affairs could not last, however. Increased population in the mines, particularly after mid-1849, created a demand for some type of allocation system.

The first change was the emergence of the idea of a "claim." Legal historian Andrea McDowell shows that the concept of a claim as an area of land, as opposed to a hole in the ground, did not become standard until 1849, although there were scattered uses of the term earlier. Within a matter of months, however, some basic rules became widely accepted, which McDowell calls the "common law or customary law of the diggings" (McDowell 2002, 15). Perhaps the most fundamental of these rules was that tools left in a hole indicated that the miner was still actively mining, and so the hole and the immediately adjacent land should not be interfered with.[5]

Soon after the idea of a claim arose, miners began to meet to set down rules for a geographic area, the mining district. Writing in the tradition of Demsetz (1967), Umbeck theorized that "as land values rise and population increases, property rights will change from a communal sharing arrangement to private property in which each individual is assigned exclusive rights to a piece of land and all the income derived from it" (1981, 48). Umbeck refers to the mining codes as "contracts," Rousseauian agreements to foreswear violence for the sake of collective gain. But district rules were not contracts in any standard sense—agreements among a list of signers to respect and enforce one another's rights.[6] Mining-district codes were "laws of the land" for a specified area, rules and procedures binding on all miners in that district, founding members and newcomers alike. In the standard narrative, the mining districts were so effective and legitimate that they persisted long after the arrival of civil government, and their codes and customs ultimately became the basis for American mining law.

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[4] As Mason wrote in his report of 17 August 1848: "Conflicting claims to particular spots of ground may cause collisions, but they will be rare, as the extent of the country is so great, and the gold so abundant, that for the present there is room and enough for all" (quoted in Paul [1966], 96).

[5] McDowell quotes from an account by miner Felix Paul Wierzbicki, written in September 1849: "A tool left in the hole in which a miner is working is a sign that it is not abandoned yet, and that nobody has a right to intrude there, and this regulation, which is adopted by silent consent of all, is generally complied with" (2002, 5).

[6] Libecap (1989, 11) extends this usage further, using the term "contracting" to refer not only to private bargaining but also to lobbying activity directed toward politicians and bureaucrats. Both authors mean to include all voluntary efforts to reduce the dissipation of rent. But their use of the term "contract" obscures the distinction between binding commitments by individuals and other forms of collective or political activity.

As one might expect in such a setting, miners drew on precedent and analogy in establishing these laws. Although the mining districts have long been celebrated as expressions of American frontier democracy (Shinn 1948 [1884]) early observers were well aware of the influence of Mexican mining law. Lawyer Henry Halleck wrote: "The miners of California have generally adopted as being best suited to their particular wants, the main principles of the mining laws of Spain and Mexico, by which the right of property in mines is made to depend upon *discovery* and *development*; that is, *discovery* is made the source of title, and *development*, or working, the condition of continuance of that title. These two principles constitute the basis of all our local laws and regulations respecting mining rights" (Halleck 1860, v).

In his 1867 treatise on mining law, Gregory Yale similarly argued that the role of American ingenuity in designing the codes had been exaggerated, in that most rules and customs were "easily recognized" from earlier mining traditions, primarily the Spanish-American system that had grown up under the ordinances of New Spain. The doctrine that claims must be worked or were subject to forfeiture, for example, was "precisely the principle of the *Ordenanzas de Mineria*" (Yale 1867, 58, 66). Mexicans were by no means dominant at the early miners' meetings, but their concepts may have had disproportionate influence because they had more experience in mining than most of the newcomers.[7]

It is not necessary, however, to view the mining codes as alien to American cultural values. As Zerbe and Anderson (2001) note, the first-come, first-served rule had strong salience as a fairness norm. Assigning ownership on the basis of "first possession" is a long-standing principle in Anglo-American common law (Lueck 1995; 1998). Nowhere was this dictum more vividly on display than in the settlement of American public lands in the nineteenth century. The Preemption Act of 1841 was the culmination of a long series of "special" preemption acts. It virtually institutionalized the practice of squatting and the principle that family-size plots would be provided to those who met settlement and improvement conditions. These analogies were frequently noted in gold rush discussions (Ellison 1926).[8] Elements of a typical mining-district code closely paralleled those of midwestern claim-clubs agreements pertaining to public land that had not yet been put up for sale: the size of claims; directions for marking, registering, and transferring claims; and procedures for settling disputes over contested claims (Bogue 1958).

Clay and Wright (2005) assembled a data set of surviving mining-district codes.[9] It included codes for 147 mining districts from the period 1849 to 1880, roughly 30 percent of all mining-district codes.[10] Because early mining districts were of

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[7] Some of the Americans had participated in earlier gold rushes in the southern Appalachians, but their numbers could have been only a small part of the total, and there is no record of mining districts in these cases, most of which took place on privately owned land. See Williams (1993) and Young (1982).

[8] See also the discussion in Libecap (1989).

[9] Many of these codes were collected for the 1880 *Report on Precious Metals* (U.S. Bureau of the Census 1880). The rest of the set was assembled from county histories, newspapers, and surviving documents. A full list of codes and sources is available upon request.

[10] In his study of mining districts, Umbeck (1981) compiled a data set of 180 mining district codes. The difference between the two data sets is attributable to the incompleteness of Umbeck's citations and the fact that some references did not include the full text. These gaps prevented Clay and Wright from using 29 of his codes, but Clay and Wright's data set includes 10 codes that do not appear in Umbeck's data set.

TABLE 3.1
Summary Statistics for 52 Codes from 1850 Through 1852

Attribute	Number with Given Attribute
Claim size	52
Number of claims held by occupation	47
Work requirements	42
Existence of a recorder	42
Allowance for sale/transfer	36
Requirement that claim be recorded	33
Marking claim	30
Dispute resolution	24
Allowing claims by company	12
Bonus for discovery	10
Boundaries of mining district	9
Exceptions for working	8
Restrictions on foreign miners	8
Definition of claim abandonment	4
Property rights in water	3
Property rights in additional land	3
Rules for calling meetings	2
Rules for changing rules	1

SOURCE: Clay and Wright (2005, 165).

interest, the primary focus was on the 52 codes written between 1850 and 1852. Table 3.1 displays the attributes most frequently found in the early codes. Limits on claim size and number, as well as work requirements, were nearly universal. A majority of the codes specified procedures for marking and recording a claim, as well as for sale or transfer. For the most part, however, these early codes were sparse and incomplete, covering only a subset of what might be considered the basic elements of a mining-claim system. Clay and Wright's interpretation of this truncation is that the codes were understood as addenda, supplementary to the customs and usages that prevailed more generally. Indirect references to recording or work requirements suggest that such conventions often prevailed on matters that were not explicitly covered. When disputes were taken to court, judges typically referred to "customs and usages of miners," as well as to "regulations," as a basis for adjudication.

In one sense, the codes suggest that property rights were relatively secure, as Umbeck (1981) has argued, and that they were supported by norms of fairness, as Zerbe and Anderson (2001) have argued. Comparison across codes confirms Umbeck's (1981) view that mining codes were adapted to the circumstances of local mining districts. Some trends, such as greater attention to defining district boundaries, were common to both placer and quartz districts, perhaps reflecting greater uniformity statewide.[11] Others, such as exceptions to work requirements, allowance for sale or transfer, and rights to water, were much more prevalent in placer

[11] Yale stated that "these customs and usages have, in progress of time, become more general and uniform; and their leading features are now the same throughout the mining regions of the State" (1867, 62).

districts, presumably because of the difficulty of satisfying work rules in placer mining.

The Regulatory Function of Mining-District Codes

Previous interpretations have drawn on analogies to production-oriented activities, such as farming, and have neglected a basic feature of the gold rush context: miners were in a race to discover a limited number of high-yield, nonrenewable deposits. Typically a miner worked a claim only long enough to determine its potential. If he decided that it was a relatively low-value claim, as most were, he continued the search for one of the legendary bonanza sites. Because miners were continually looking for new and better sites even as they worked their present holding, mining-district rules were as much concerned with procedures for abandonment and re-possession of claims as they were with protection of the rights of holders of existing claims.

Although the analogy to farmland informed the design of the miners' codes, the effects in the two cases were quite different. Whereas squatters' rights and preemption rights were intermediate stages on the path to fully established ownership rights, such an evolution did not occur in the gold-mining districts. In understanding this divergence, one clue lies in a third widely accepted norm found in nearly all the early mining codes, the requirement that a claim must be worked to be maintained. Although work rules in gold mining were ostensibly only a logical extension of preemption-homestead principles, they compelled districts and later the courts to define "work." They also had to identify legitimate reasons for nonwork, such as illness or lack of water, which generated an endless stream of disputes and litigation. The system had some resemblance to the common-law doctrine of adverse possession, according to which property can be occupied and claimed if the original owner does not take active steps to evict trespassers (Lueck 1995). But on the spectrum from secure property rights to use-it-or-lose-it, the mining codes were at an extreme end in favor of the latter. Any slacking of effort on the miner's part exposed him to charges of having abandoned the claim. Prior occupation was not sufficient to re-possess a claim; the plaintiff also had to demonstrate that he had in fact complied with district work rules. Otherwise, the claim was liable to be "jumped," a standard procedure for entry into gold mining that was legitimated by the mining codes.

Clay and Wright (2005) argue that the main historical features of mining districts may best be understood by viewing them as institutions for managing access to mining sites in a high-turnover setting that approximated open access. As McDowell (2002; 2004) notes, participation in miners' meetings was not restricted to claim holders.[12] Typically, the codes begin with an announcement such as the

[12] There are some possible exceptions to this statement. The 1856 codes for both Little Humbug Creek and Maine Little Humbug state: "No person shall have voice or vote in a miners meeting or at arbitration that occurs in this mining District except he either holds a claim or is working in this mining district" (U.S. Bureau of the Census 1880, 291, 292). Clay and Wright interpret this as an exclusion of nonminers, but not a restriction to claim holders. The Empire Hill code was extended by one year "at a meeting held pursuant to a call by the claim holders" (U.S. Bureau of the Census 1880, 343); but the report of the next year's meeting uses the customary phrase, "a meeting of the miners." The only true documented case seems to be the Illinoistown quartz district code of March 1863, which barred persons who were not claim holders from future meetings (U.S. Bureau of the Census 1880).

following: "At a meeting of the miners of Union Quartz Mountain, held this 30th day of February 1851 . . . the following Rules and Regulations were unanimously adopted" (U.S. Bureau of the Census 1880, 332). The internal politics of these early meetings cannot be recovered with any precision. If the group were divided between claim holders and latecomers without claims, it seems apparent that the only way to secure the votes of the latter was to assure them that the early arrivers would not be allowed to appropriate the entire district indefinitely. Both the provisions of the codes and their operation in practice suggest that a primary objective was not to strengthen the security of existing claims, but to place reasonable limits on those claims by setting explicit standards that an incumbent must meet to retain a claim against new arrivals.

McDowell (2002) advances a subtler argument. She suggests that whether they held claims or not at a point in time, miners operated behind a Rawlsian "veil of ignorance," visualizing themselves as claim jumpers as easily as claim protectors. This proposition is interpreted here as reflecting the pervasiveness of the "search" and "race" aspects of gold mining. The key difference between mining districts and claims clubs or cattlemen's associations was that gold mining was a race to find a small number of high-payoff claims. To be sure, search activity was inseparable from production, because only by the hard work of digging and sluicing could a miner-prospector learn whether a particular location was worth pursuing or not. Meanwhile, the "race" aspect was intensified by the keen awareness that high-yield gold sites were limited, gold was depletable, and many others were looking for the same limited number of deposits. If these features of the situation were paramount, it is perhaps understandable that mining-district codes made relatively little attempt to exclude new entrants and favor incumbents. In essence, they acquiesced in the high-turnover state of affairs and focused instead on prescribing rules for the orderly turnover of mining sites.

Even from a cursory reading, it is evident that the codes devoted as least as much attention to restrictions and requirements on claim holders as to protecting their rights. For example, the code for the Poverty Hill, Yorktown, and Chili Camp in Tuolumne County, adopted on 6 September 1851, contains nine articles. Two of these place size limits on claims; two restrict the number of claims that may be held; another sets down stringent marking procedures; and two others require that the miner be present and working the claim if water is available.[13] These rules hardly qualify as a pledge of mutual protection by property owners. But in the gold rush context, they can be understood as a codification of the rights of a larger group of would-be claimants.

To be sure, mining codes varied in the extent to which they favored claim holders over prospective jumpers. One of the oldest surviving codes, for the Gold Mountain Mining District in Nevada County (passed on 30 December 1850), might be considered proholder. It allowed claims to be held without tools being left or work being done until the first day of April 1851, and it provided stiff penalties for anyone who "takes away or uses tools of another without permission," or who "throws

[13] This code is recorded in the *Miners and Business Men's Directory* (1856). The remaining articles provide for exceptions when a person discovers a new lead, or when a claim is located on a ditch or ravine that has formerly been worked. In the latter case, ditch digging can qualify as labor sufficient to hold the claim.

dirt or rock upon the claim of another." Apparently influence had swung to the other side a year later, however, because the revised version required that claims be recorded by October 1851 "on pain of forfeiture" and severely tightened the rules for marking a claim.[14]

Subsequent Legal Developments

The endogenous development of a system of property rights that provided a reasonably stable framework within which search and production could occur shaped subsequent U.S. mining law decisively. Federal mining laws of 1866, 1870, and 1872 largely confirmed what by then was a well-established "free mining" precedent, dashing hopes that public-domain mining might be a major federal revenue source. In his exhaustive review of international mining laws, Theodore Van Wagenen (1918) concluded that prospecting was nowhere else as free as in the United States. In his study of comparative resource property rights, Anthony Scott (2008) concurs: "Essentially, for much of the nineteenth century, the American government acted as though it regarded mining law primarily as an instrument for bringing about an equitable and orderly disposal of the public lands" (2008, 286). These policy choices reflected not merely persistent mining-camp culture, but also political pressure in California and elsewhere in the West for rapid development of mineral resources. Although this perspective is often referred to as the "mining interest," it largely represented the interests of those who stood to gain from expanded mineral production, such as merchants, developers, and producers of mining equipment. The distinction is illustrated by the enactment of the foreign miners' tax by the California legislature in April 1850, imposing a $20 monthly license fee on all noncitizen miners in the state. After a chorus of opposition from merchants and editors, the tax was repealed in the following year and was reenacted at a more moderate rate in 1852. As mining activity spilled out from California into other western states and territories, and from placer gold to a range of hard-rock minerals, political priorities of both legislatures and courts favored rapid exploitation of mineral wealth (Bakken 1988; Libecap 1978).

The Federal Government as Mining Promoter

Rather than an extractor of rents, the U.S. federal government became a primary promoter of regional development through investment in the infrastructure of geological knowledge. In 1867 Clarence King, who had worked for the first state geological survey of California after graduating from the Sheffield Scientific School at Yale, approached the Corps of Engineers with a proposal that the War Department allocate funds for the geographic exploration of the fortieth parallel. The first publication from this project appeared in 1870, with contributions not just on the location of gold and silver deposits, but also on methods and equipment for digging and equipment for treating ores at the Comstock. The report was praised by the *American Journal of*

[14] "[E]very claim shall have a center stake driven upon it, which shall be three and a half inches in width by one in thickness of the length of two feet and which must be driven at least one half of its length into the ground" (U.S. Bureau of the Census 1885, 331).

Science as "the most valuable contribution yet made to the literature of the Mining Industry of the United States" (quoted in Manning [1967], 9).

When King exposed a fraudulent mining scheme in which an area had been secretly seeded with uncut diamonds, the *San Francisco Bulletin* lauded "the practical value, in the ordinary business of society, of scientific education and research . . . These public surveys 'pay' in more senses than one, and even those who care nothing for wider and fuller knowledge for its own sake, must hereafter admit that Government spends no money more wisely and usefully" (quoted in Manning [1967], 10–11). King was subsequently besieged by offers to examine property, and according to a friend, "He never charges less than $5000 to look at a mine" (Spence 1970, 113–114).

The United States Geological Survey, which emerged in 1879 under King's direction as the consolidation of several separate projects, became a leading center for topographic and metallurgical research in the post–Civil War era. The survey soon became known as a valuable employer for young men beginning a career in the industry, a "great graduate school of instruction," in the words of a mining journal (Spence 1970, 60). In 1882, under King's successor J. W. Powell, the survey was authorized to extend its operations east of the Mississippi and to begin preparation of a geological map of the entire country, not just the public domain. Thus it may fairly be said that the California gold rush enhanced and encouraged development of the entire national minerals sector, not just of the western region (David and Wright 1997).

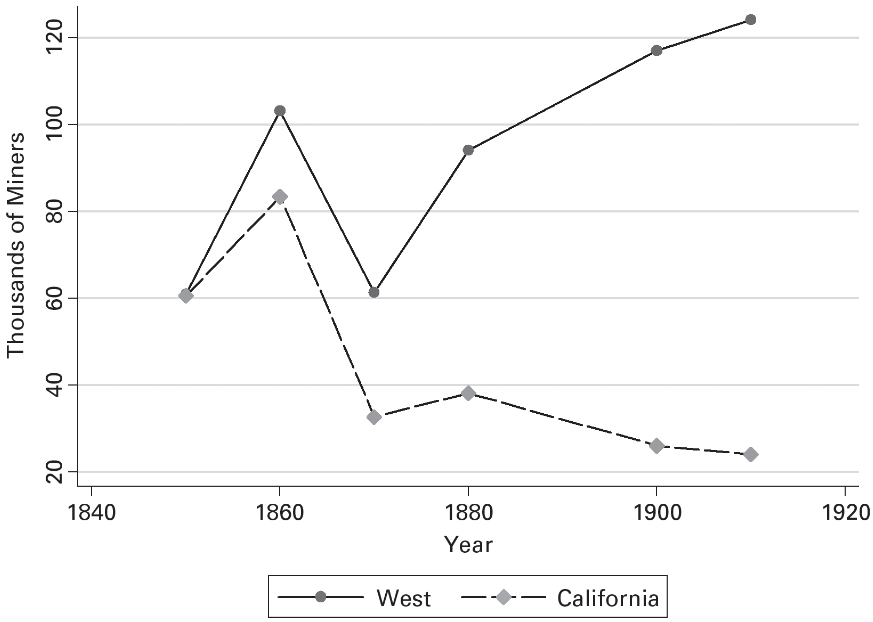
Growth of the Minerals Sector

The result of this open and accommodating institutional setting was a vast expansion of activity in the minerals sector of the economy. The gold rush jump-started the western regional minerals enterprise. Figure 3.1 shows the evolution of the number of miners in the West over time (those in the East almost exclusively mined coal). The number of western miners fell between 1860 and 1870 and then began a steady rise in the 1870s. Opportunities in California declined as production shifted from surface mining of placer gold to more mechanized subsurface mining of quartz gold, but many miners migrated to other western states. Figure 3.2 shows that more than 20 percent of adult males were miners at some point in the history of six western states: California, Arizona, Colorado, Idaho, Nevada, and Montana. In every case except Arizona, miners were the largest share of the population in the first year of enumeration. For example, in 1860 they were 35 percent of the adult male population of Colorado and 56 percent in Nevada; in 1870, miners were 60 percent of adult males in Idaho and 49 percent in Montana.[15] Mining clearly drove settlement of these states. One can see this in maps of population distribution. The first map of this type was produced by the Census Bureau in 1870 and shows that the population in California, Colorado, Idaho, Nevada, and Montana was clustered in key mining districts.

[15] Percentages calculated from 1850–1910 public use samples of the census of population. Adult males are all aged 15 to 60.

FIGURE 3.1

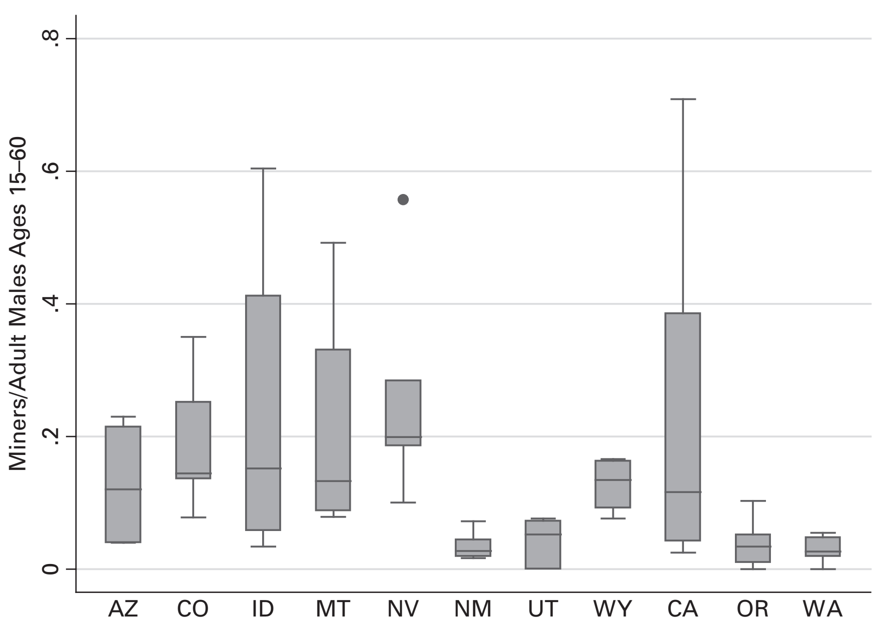
Miners by Census Year



SOURCE: Authors' calculations based on the 1850–1910 public use samples of the census of population's occupation variable.

FIGURE 3.2

Miners as a Share of Adult Males, 1850–1910



SOURCE: Authors' calculations based on 1850–1910 public use samples of the census of population. Adult males are all aged 15 to 60. The bars show the range of values for each state, while the boxes display the median, 25th and 75th percentiles, and adjacent values. The dot reflects an outlier year in which the percentage fell outside the upper adjacent value.

TABLE 3.2
Immigrants Reporting Occupation as "Miner"

Years	Number
1820–1824	15
1825–1829	241
1830–1834	371
1835–1839	41
1840–1844	110
1845–1849	719
1850–1854	8,844
1855–1859	25,792
1860–1864	18,309
1865–1869	35,001
1870–1874	26,387
1875–1879	12,128
1880–1884	26,312
1885–1889	24,135
1890–1894	20,553

SOURCE: U.S. Department of the Treasury, Bureau of Statistics (1903), 4406–4411.

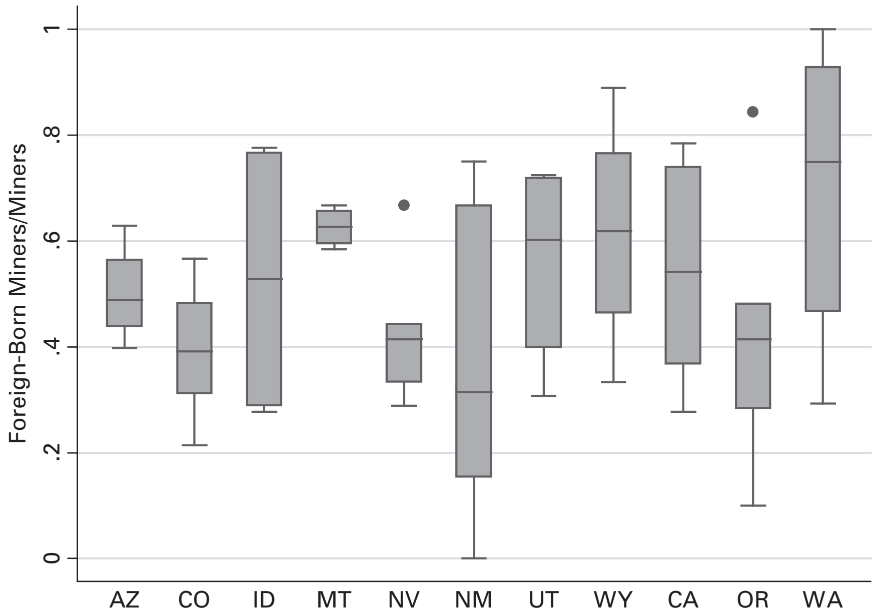
Many of the western miners came from overseas. Table 3.2 shows the number of immigrants to the United States who gave their occupation as "miner" at the time of entry. The lasting impact of the gold rush is evident. Fewer than 2,000 miners entered the country before 1850, but more than 35,000 did so during the gold rush decade. Miner immigration actually increased during the 1860s and remained high for the rest of the century. Figure 3.3 shows that the share of foreign-born miners was high in most mining states in most years. Figure 3.4 shows the distribution of nationalities of all foreign-born miners from 1850 to 1910. The largest share was from the United Kingdom (England, Ireland, Scotland, and Wales). Chinese miners were the second-largest share, followed by Nordic, Mexican, Italian, German, Canadian, and other nationalities.

Although there is no way to measure their prior experience, many of these foreigners brought expertise that was highly valued in mining areas. In 1850s California, it was considered a great advantage to have a Cornishman or a Chilean in one's party. The shift to quartz mining further increased the prominence of skilled foreigners because of their experience at sinking and timbering shafts to reduce risks of rock falls or "caves" and their expertise in ore-reduction processes such as pulverizing rock. Cornishmen were held in particularly high esteem and were favored for positions both as miners and managers (James 1994; Paul 1947; Rowe 1974).

Figure 3.5 shows the course of gold production over time. The California series displays the classic pattern of a rush to discover a fixed number of rich ore deposits: Production peaked along with the number of miners in 1852 and drifted downward until 1865. But a focus on a single state is somewhat misleading because exploration spread to other western states, primarily Nevada and Colorado. Their rising gold production partially replaced California's declines. After 1885, total national

FIGURE 3.3

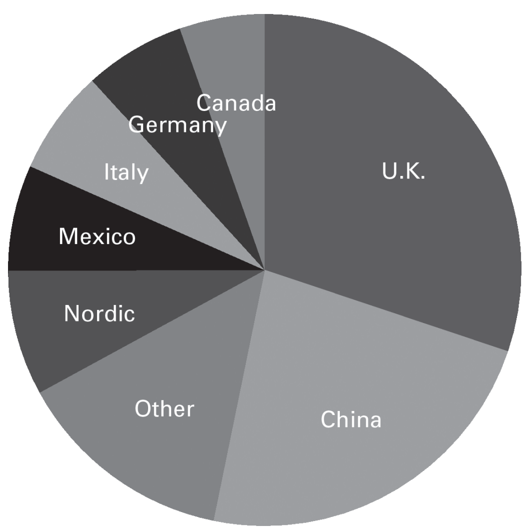
Foreign-Born Miners as Share of All Miners, 1850–1910



SOURCE: Authors' calculations based on 1850–1910 public use samples of the census of population. For an explanation of the diagram, see notes for Figure 3.2.

FIGURE 3.4

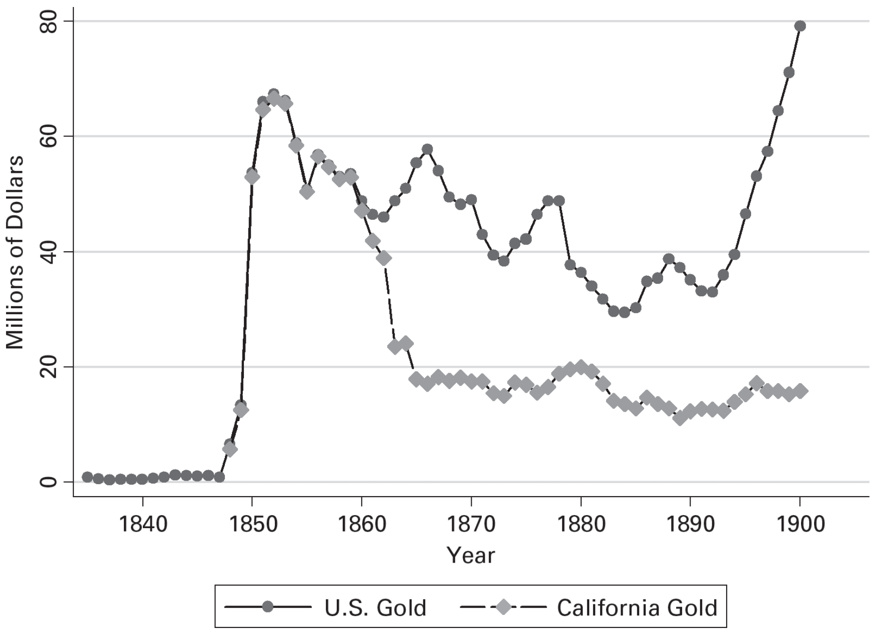
Nationalities of Foreign-Born Miners, 1850–1910



SOURCE: Authors' calculations based on 1850–1910 public use samples of the census of population.

FIGURE 3.5

Gold Production, California and U.S. Totals, 1835–1900 (in millions of dollars)



SOURCE: Berry (1984, 74, 76, 78).

gold production began to rise and by the 1890s had surpassed the peaks of the gold rush era.

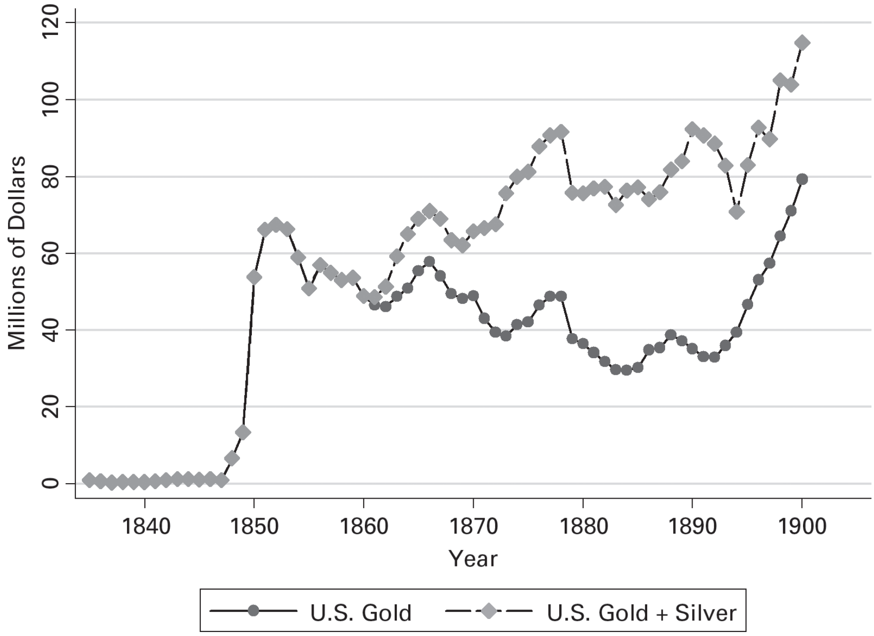
But silver mining in the West was also a direct consequence of the California gold rush. The discoverers of the fabled Comstock Lode in what is now Nevada were gold prospectors who inadvertently stumbled on silver. Placer miners from California had worked a gulch called Gold Canyon for some years, unaware of the riches under their feet. Only in 1858, when more knowledgeable diggers detected bluish quartz mixed with the gold dust and had it assayed, was the area discovered to be rich in silver. A newspaper notice in July 1859 kicked off the Comstock rush, which in turn triggered searches for silver throughout the territories. Nevada became known as the Silver State, but its silver output was soon surpassed by that of Colorado, Montana, and Utah (Smith 1998 [1943]).

Figure 3.6 shows the dramatic growth of silver after 1860. If gold is combined with silver, the picture that emerges is not one of boom and bust, but of nearly steady growth throughout the century and beyond. From this perspective, the years of decline in California gold constituted a relatively minor setback in the larger story of expansion.

But the linkages did not stop with the transition from gold to silver. As the mining frontier progressed from west to east, prospecting became a specialized activity, conducted in small organized parties. These parties consisted of anywhere from five to fifty men, and experienced Californians were particularly prominent. Butte, Montana, became a gold placer camp in 1864 as the result of one such expedition. The camp became nearly deserted as the placers were exhausted, but interest in

FIGURE 3.6

U.S. Silver and Gold Production, 1835–1900



SOURCE: Berry (1984, 78).

Butte was revived in 1875 after some rich silver discoveries, by then a familiar object of mining attention. Butte silver was sufficiently promising to induce the Walker brothers of Salt Lake City to send their associate Marcus Daly, formerly a mine foreman on the Comstock Lode, to the area to examine and purchase claims. Early indications of plentiful copper deposits in the area were neglected at first, as they were elsewhere in the West. Rodman Paul observes, "Just when Daly came to realize that his silver mine was in fact one of the richest copper mines in the world, is not clear" (1963, 147–148). But by 1882 Daly induced a San Francisco group to finance a major investment in mining and smelting copper on a mass-production basis. By 1887 Anaconda was the largest copper mine in the country, propelling the United States into world leadership in copper production. Figure 3.7 shows that when copper is included, the path of post–gold rush mineral expansion in the West was almost continuously upward. Through similar path-dependent processes of discovery and learning, the value of base-metal production in the West (chiefly copper, lead, and zinc) came to exceed that of the precious metals by the 1890s.[16]

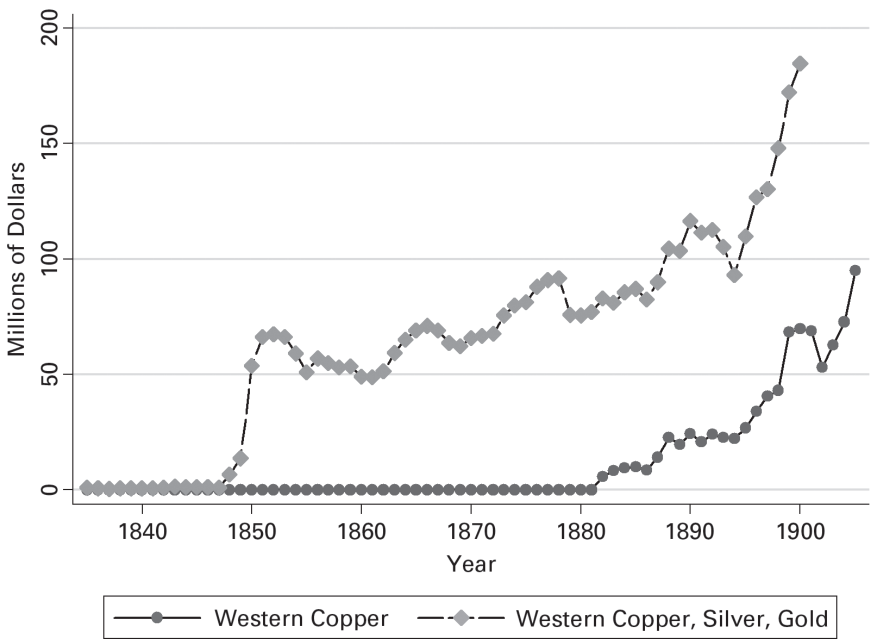
Inputs, Outputs, and Learning

To be sure, much of this expansion can be interpreted as the rise of inputs as much as of outputs, and from this perspective, one may question a linkage to common notions of a knowledge-based sector. But gold mining was technologically dynamic

[16] This paragraph draws on Richter (1927) and Trimble (1914).

FIGURE 3.7

U.S. Silver and Gold Production, plus Western Copper, 1835–1900



SOURCE: Data based on *The mineral industry: Its statistics, technology and trade*. Annual volumes, 1892–1905.

virtually from the beginning of the rush, so that the efficacy of mining labor improved over time despite ongoing depletion at particular deposit sites. Furthermore, the geographic expansion of the mining frontier was itself a learning process, deploying increasingly sophisticated forms of exploration and adaptation to new types of ore bodies and minerals. Perhaps most important, there was a positive complementarity between these two sources of progress: exploration brought new discoveries and technological challenges, while improvements in techniques of extraction, ore separation, and refining in turn facilitated the extension of mining into locations and ore qualities that would otherwise have been unprofitable, in effect creating new mineral resources from an economic standpoint.

The earliest placer miners extracted the metal from the gravel with a circular hand method performed by a single man with a pan. As early as 1848, miners began to make use of a larger machine called a "rocker" or "cradle," with which three or four men working together could produce a larger volume of "dirt" in a day. During the winter of 1849 to 1850, the "long tom" was first introduced in California. This instrument was a still-larger version of the cradle, with two 12-foot sections operated by three to six men, and required a continuous stream of water. Because the long tom allowed many of the finer gold particles to escape, a further improvement was implemented the following year in the form of the "sluice" or "sluice box," an open trough with riffle boxes perforated to allow gold particles to lodge. By the later part of 1849, all these techniques were enhanced by the use of quicksilver or mercury for more efficient separation of gold from the sand. Historian Rodman Paul argues that this package of innovations, together with investments in canals and ditches, constituted "a complete revolution in mining," and he notes that reductions in the unit cost of materials allowed miners to "extend their work into comparatively low-grade auriferous ground that had not previously been considered rich enough" for exploitation (1947, 65).

At that early stage, one could hardly have claimed that California mining technology was more advanced than elsewhere in the world. The use of mercury in gold mining was ancient, and the transition from panning to rockers to sluices did little more than recapitulate similar progressions in smaller previous rushes in Georgia and North Carolina. But even if one gives due allowance to all these considerations, one may still detect an emerging American pattern of progress in the minerals sector, in which higher-order forms of knowledge were deployed to address new technical challenges, and relationships between mining and other industries became increasingly complex.

Many of these linkages were functions of the scale of the mining sector. The rise of hydraulic mining in the late 1850s extended the range of accessible placer gold, albeit at high environmental cost, and dramatically increased the industry's demand for capital equipment (Isenberg 2005). Leather hoses for mining began to be made in San Francisco in 1857 and soon were exported to fire departments around the world. For quartz mining, San Francisco foundries and machine shops produced drills, belts, cables, explosives, pumps, and steam engines. The 1870 census recorded 42 steam engines in California mines and 604 in manufacturing firms. Manufacturing per capita in California was well ahead of that of midwestern states like Ohio and Illinois, and many industries that originated to serve the mines developed technologies with multiple additional uses, for example, in cable cars, shipbuilding, hydroelectric power, and sugarcane processing (St. Clair 1999).

Linkages from minerals to technology and science were accentuated with the shift from placer to quartz mining, and even more so with the rise of silver mining on the Comstock and elsewhere in the West. Barger and Schurr write that silver "ended the poor man's day in mining and ushered in the era of the financier and the engineer" (1944, 101). An important example of innovation endogenous to these new challenges was square-set timbering, in which rectangular sets of timbers replaced the ore as it was removed, increasing the strength of support and making possible the development of large underground ore bodies. The system was invented in 1860 by a German engineer who had been in California since 1851, and it soon became standard throughout the Comstock, an object of study and imitation by visiting experts from around the world (Paul 1963).

Of equal importance was a stream of innovations in methods of working ores that extended the intensive mining frontier for complex ores and low-grade deposits. An early breakthrough was the Washoe pan amalgamation process for separating silver and gold, developed in 1862 by the 49er Almarin Paul, who began by transferring stamp-mill technology from California quartz mining and then extended it to incorporate heavy iron mullers that would grind as well as mix the pulverized rock. Although standard historical narratives identify Paul and the Washoe process as the key breakthrough, he was only the most successful of the many gold rush veterans who were experimenting along related lines. Nor did the processes of innovation and adaptation stop there. For example, when the Washoe process was found not to work well for ores with arsenic or antimony sulfides, a variant known as the Reese River process (in which the ore was roasted with salt to convert silver sulfides into silver chlorides) was developed and used in a number of new silver-mining districts. In the 1860s and 1870s, the Comstock became known as a world center for hard-rock mining techniques, the "mining school of the world" (Barger and Schurr 1944, 102; Paul 1963).

Roughly simultaneous with the Comstock, but posing special geophysical challenges, was the gold- and silver-mining industry of Colorado. Although miners flocked to the area in large numbers between 1859 and 1865, output growth was inhibited by the extreme depths of the ores, and even more by the fact that Colorado gold ores were found in chemical combination with sulfides, known as "sulpherets" or "refractory ores" that resisted amalgamation. Initially, the main adaptation was a local variation of the California stamp mill that gave the ores a longer and finer crushing and a longer exposure to the action of mercury. These engineering methods were inherently limited in their ability to cope with what was in essence a scientific or metallurgical problem. As a mining newspaper wrote in 1870, "In Colorado we are having the privilege of solving some of the most difficult problems of metallurgy" (quoted in Paul [1963], 123). Numerous pseudoscientists, often self-titled professors, offered contraptions and processes to credulous mining companies. This led Rossiter Raymond, the U.S. commissioner of mining statistics, to declare that "desulphurization became the abracadabra of the new alchemists" (quoted in Fell [1979], 9).

Ultimately, Colorado investors reached out to real scientists for a solution, recruiting Nathaniel P. Hill from Brown University, an applied chemist who also maintained a vigorous consulting business. After visiting Colorado and gaining an appreciation of the technical challenge, Hill made trips to Britain and continental Europe to study techniques for smelting ores. In 1868 Hill built a smelter, largely copied from one in Wales. Its costs were prohibitively high, however, and the major breakthrough came only in 1871, when Hill allied himself with Richard Pearce, son of a Cornish miner who had studied both at the Royal School of Mines in London and in Freiberg. Their success provides a striking example of deployment of world-class scientific knowledge in the solution of a regional mining problem. Remarkably, Pearce's method was never patented but remained a company secret for the next 33 years.[17]

Hill's firm quickly drew the attention of the scientific community. James D. Hague visited the plant in 1868 as part of his geological study of the fortieth parallel and published data provided by Hill as part of Clarence King's study of the region. Pearce's technology was then discussed extensively in the first issue of the *Transactions of the American Institute of Mining Engineers* in 1871. In the *Transactions* for 1876, Thomas Egleston of the Columbia School of Mines published an article that discussed every aspect of the firm's technology except the secret process (Fell 1979).

[17] This paragraph draws on Fell (1979) and Paul (1960).

Successful development of Colorado smelting set the stage for the silver discovery at Leadville in 1877, a bonanza that was in many ways endogenous to the emerging regional technology. Leadville in turn became one of the first priorities of the United States Geological Survey (USGS), newly established in 1879. The USGS monograph on Leadville, prepared under the leadership of Samuel F. Emmons and published in 1882, was known for years as "the miners' bible." Paul writes: "More than any other event, the publication of this scientific study convinced skeptical mining operators that they could learn something of cash value from university men" (1960, 47). Emmons's thorough geological study of the entire district within a 10-mile radius generated a comprehensive view of the structural conditions affecting the distribution of ores. The survey's capacity to elucidate an area's complex system of faults led in turn to discoveries at Aspen and Rico, continuing the pattern of dynamic interaction among geological learning, processing technology, and new discoveries (Rickard 1932). Within a few years, other mining districts were petitioning the USGS for similar surveys.

The dynamic swung back to gold in the last decade of the nineteenth century with the invention and subsequent perfection of the cyanide process of gold extraction. A patent for a cyanide process was issued as early as 1867, and the pace of innovative effort accelerated in the 1880s. But the first demonstration of the commercial feasibility of cyanide was by the Scottish chemist John Stewart MacArthur, who obtained a British patent in 1887 and brought the process to Colorado in 1889. As with many metallurgical innovations, the process required extensive adaptation to local variations in ore quality. Between 1889 and 1905, 80 American patents were approved for various methods of extracting gold by cyanide, and the litigation was as intense as the experimentation. Ultimately, however, cyanide brought the required gold content of tailings down to as low as $1.80 per ton, leading to the "rediscovery" of many previously abandoned mines. The process also greatly increased the demand for technical skill and created a new niche for the metallurgical engineer, now clearly distinguished from assayers performing routine lab tests (Monroe 1905; Spude 1991).

The Rise of Western Copper

As previously mentioned, copper discoveries in Montana stemmed from the same exploratory process that spread gold and silver mining throughout the western states, which was traceable in turn to the California gold rush of the 1850s. Development of the region's potential in copper mining further extended the organizational and technological trends previously noted: greater capital intensity in mining operations, larger-scale enterprises, and complementary knowledge-intensive advances in ore processing and exploration. By 1884 the United States surpassed Chile as the world's leading copper-mining nation.

According to Richter (1927), the two most important innovations in American copper metallurgy during this period were the use of the Bessemer process for copper converting and the introduction of electrolysis for the final refining of copper. Converting brings copper matte forward to blister copper, a process that formerly required several melting or smelting operations plus roasting; the Bessemer pneumatic converter reduced the process to a single operation in a few hours. Electrolysis allowed virtually complete recovery of the metal content of copper bullion, matching the naturally pure copper of the Lake Michigan district. In the early twentieth century, these metallurgical advances were further extended by the use of the oil-flotation process in concentrating the ore. Oil flotation called for and made possible extremely fine grinding, which reduced milling costs sufficiently to allow the exploitation of low-grade porphyry copper ores on a commercial basis (Schmitz 1986).

Thus, advances in metallurgy effectively created new American mineral resources by fostering rediscoveries of deposits long known but considered submarginal. Indeed, there was an exponential link between the reduction in required yield and the expansion of ore reserves, a regularity known as Lasky's law, an inverse relationship between the grade of the ore and the size of the deposit (Lasky 1950; Schmitz 1986). Because the economies were in processing, commercial exploitation of this relationship encouraged large-scale, nonselective mining methods, using highly mechanized techniques to remove all materials from the mineralized area. This approach was developed by Daniel Jackling, who graduated from the Missouri School of Mines in 1889 with a degree in metallurgy. In effect, Jackling's method was an application of mass-production, high-throughput technology and organization to mining. But this technology transfer between sectors was enabled by a prior revolution in copper metallurgy.

From this perspective, reductions in average ore grades are a measure of technological progress rather than depletion, especially in light of the downward trend in the real price of copper during this period. In her 2009 master's thesis, Kathryn Woodward assembled data on ore grades from the records of mining firms in Arizona, Michigan, and Montana between 1889 and 1909. Woodward's results are displayed in table 3.3. The inverse relationship between declining grades and expanding production in the western states is evident. By contrast, in copper-rich Chile, where

TABLE 3.3

Copper Production and Ore Grade, 1889–1909

		Copper Production (pounds)	Grade (%)
Arizona	1889	32,139,529	10.33
	1902	119,841,285	5.85
	1909	291,110,298	4.43
Michigan	1889	87,413,000	1.80
	1902	170,194,996	1.10
	1909	231,870,496	1.08
Montana	1889	104,189,353	8.56
	1902	266,500,000	4.33
	1909	314,858,291	3.03

SOURCE: Woodward (2009, 33). Production and grade for 1889 are from U.S. census data. Grades for 1902 and 1909 are averaged from firm data.

output was stagnant, yields averaged between 10 and 13 percent between 1880 and 1910 (Przeworski 1980; Woodward 2009).

Higher Mining Education

The expansion of mining and consequent encounters with new technical and scientific challenges gave rise to indigenous training institutions adapted to American conditions. The earliest efforts antedated the gold rush. For example, the Lawrence Scientific School at Harvard included mining and metallurgy as part of the founder's intended purpose in 1847. In practice, the Lawrence School concentrated on pure-science aspects of biology and chemistry. Before the late 1860s, Americans who wanted advanced training in mineral sciences were likely to enroll in one of the prestigious European mining colleges in Sweden, Freiberg, or Paris.[18] The first growth spurt for domestic mining schools came only in the 1860s (David and Wright 1997).

Although several of the eastern schools had strong links to in-state mining activity, the most successful of them all had no such connection, but was clearly producing mining engineers for a national market. When Columbia College in the City of New York opened what became the nation's first successful school of mines in 1864, twice as many students (29) appeared on the first day as had been expected. Within a year, that number had more than doubled. Visitors were impressed by the rigor of the Columbia curriculum; one of them wrote in 1867: "A graduate of the School of Mines will be well worthy of his degree" (quoted in Spence 1970, 38). The first-year curriculum included courses in drawing, stoichiometry, mathematics (analytic geometry and calculus), physics, electricity and magnetism, inorganic chemistry, quantitative analysis, mineralogy, and French and German. The second year added metallurgy, mechanics, geology, botany, and mining engineering (machines). The third year continued metallurgy and quantitative analysis and added the theory of veins, assaying, and "conservation of force." A well-informed 1871 survey declared Columbia "one of the best schools in the world—more scientific than Freiberg, more practical than Paris" (Church 1871, 79; Read 1941; Spence 1970).[19]

The Columbia School of Mines was dominant for the next quarter century. In 1893 Samuel B. Christy, a professor of mining and metallurgy at the University of California, noted that the United States had more mining students than any country in Europe except Germany, and nearly half of the national total as of that year had studied at Columbia (Christy 1893; figure 3.8). Notwithstanding the academic rigor of its program, the school also sought to expose its students to practical aspects of the mining industry. Professor Robert H. Richards developed the Mining Laboratory, where problems in ore dressing and metallurgy could be worked out by students. Professor Henry S. Monroe developed the Summer School of Practical Mining, which helped students become familiar with working conditions they would meet after graduation (Christy 1893).[20]

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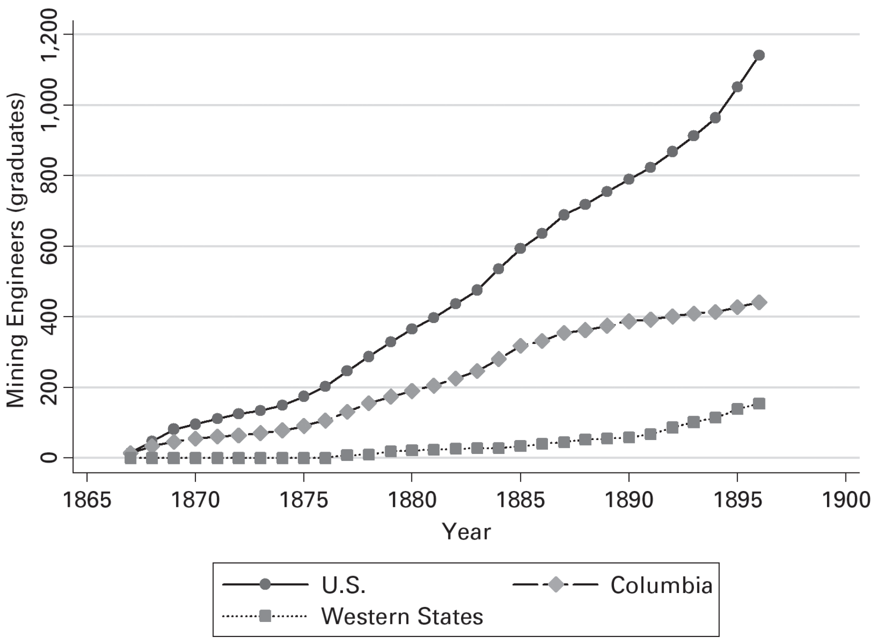
[18] Read (1941) presents a list of Americans enrolled.

[19] Read (1941) reports the opening-day enrollment at Columbia as 24 and enrollment in 1865–1866 as 97; Spence (1970) puts the opening-day figure at 29, followed by 79 in 1865–1866.

[20] Columbia College catalogs (1754–1894) are accessible through Google Books.

FIGURE 3.8
Cumulative Mining Engineering Graduates, Columbia and Western Mining Schools, 1867–1896



SOURCES: Data based on *Engineering News* (1892, 140); Wadsworth (1997, 731).

The majority of Columbia graduates stayed in the East, but many found work throughout the western states. They were sufficiently numerous in Colorado by 1884 for the School of Mines Alumni Association to establish a branch in Denver. The school journal reported Columbia clusters in Colorado, Utah, California, Arizona, Nevada, and Mexico, and many more traveled to the West on consulting trips. Clearly, Columbia was supplying mining expertise for a national market.[21]

Nonetheless, demands arose over time for mining schools in closer proximity to the mining districts. These efforts were an expression of state developmental impulses dating from the early nineteenth century, combined with the undeniable geographic specificity of much of the relevant knowledge about minerals. Inspired by the gold rush, many states initiated or revived geological surveys in the 1850s. When an 1867 proposal by a Nevada senator for a national school of mines was unsuccessful, the states quickly moved in. The Colorado School of Mines was the first to be set up as a separate institution; it was established by the territorial legislature in 1870 and began instruction in 1873. Mining education at the University of California began in the 1860s, although the first degree was not awarded until 1873. Mining schools were also established in Missouri, Michigan, South Dakota, Arizona, Nevada, and New Mexico. At Berkeley, registration at the mining college grew tenfold between

[21] Reports in the *School of Mines Quarterly*, summarized in Spence (1970).

1893 and 1903, supporting the school's claim to be "without doubt the largest mining college in the world" (Read 1941, 84; Spence 1970).[22]

Professionalization in American mining engineering was well ahead of its counterpart in Great Britain. Founded in 1871, the American Institute of Mining Engineers (AIME) was one of the earliest professional organizations, second in engineering only to the American Society of Civil Engineers. At the first meeting of the British Institution of Mining and Metallurgy in 1892, the organizers "found it more than a little irksome to have to acknowledge that in the U.S. some such organization had been operating successfully for nearly twenty years." The difference may have been mainly a matter of the scale of the national industry: whereas the AIME by that time had more than two thousand members, Britain "would be hard pressed to muster more than a couple of hundred" (Wilson 1992, 8–9).

Of course, advanced degrees and professional organizations do not necessarily imply that mining engineers and other scientifically trained personnel actually had a significant impact on mining technology and practice. But testimony is abundant that there was indeed a transition from reliance on the skills of apprenticeship-trained "mining captains," often foreign born, to deployment of college-trained engineers. The extension of the mining frontier to lower-quality ores was driven by scientific advances in geology and metallurgy and by a complementary technological shift toward nonselective mass-production methods, and both of these trends coincided broadly with the eclipse of traditional miners' skills in favor of those of professional engineers. The acceptance and legitimation of mining engineers is perhaps best indicated by their increasing presence in managerial and executive roles within large firms, an expected career path that came to be reflected in the curricula of mining schools.[23] But the high mobility and professional status of mining engineers gave them substantial independence, as confirmed by offers of extravagant salaries and bonuses to American engineers and metallurgists from such faraway locations as South America, Australia, Africa, Siberia, and China. A turning point in Australia's mining history came with the decision in 1886 to recruit high-paid engineers and metallurgists from the Rocky Mountain states, such as William H. Patton from the Comstock Lode and Herman Schlapp from the smelting towns of Colorado (Blainey 1969; Spence 1970).[24]

Property Rights and the Minerals Knowledge Economy

This chapter has argued that the American minerals sector of the late nineteenth century displayed many of the attributes associated with a knowledge economy: competitive research universities responsive to the private sector; entrepreneurial scientists and engineers who operated through active professional networks; government support for an infrastructure of public knowledge; and economic progress based on advances in the knowledge frontier. Most historical accounts date such

[22] Hendrickson (1961) lists state surveys.

[23] The association between the shift to nonselective mining methods and the rise of mining engineers is argued by Hovis and Mouat (1996). On the incorporation of administrative as well as technical skills at the Colorado School of Mines and elsewhere, see Ochs (1992).

[24] Harvey and Press (1989) note that large firms often opposed the trend toward mobility and independence on the part of engineers by imposing secrecy agreements in contracts.

developments only from the turn of the twentieth century, with the appearance of corporate laboratories and the emergence of research universities as a self-conscious group. This emergence is marked by the founding of the American Association of Universities (AAU) in 1900.[25] But the "modern" character of economic relationships in American minerals is impressive and suggests that many features of the twentieth-century "American innovation system" began much earlier in this sector.

What lessons does this analysis offer for assessing the relationship between property rights and natural resources? Most discussions of this matter deal mainly with efficiency in resource allocation in the presence of common-pool issues and other externalities. From this perspective, an open-access regime, such as that represented by U.S. mineral law, would lead to wasteful rent dissipation through excessive haste and costly, duplicative investments of labor and capital. The California gold rush displayed many of these symptoms (Clay and Jones 2008; Clay and Wright 2005). For the rest of the nineteenth century and beyond, the U.S. minerals sector was plagued by problems of high transaction costs, nuisance suits, overlapping claims, chronic litigation, and exorbitant legal fees, to say nothing of extensive environmental damage (Gerard 2001; Leshy 1987). Mining historian Clark Spence asserts: "No industry in any country was ever subject to as much or as complicated legal activity as mining in western America" (Spence 1970, 107).[26] But with all these shortcomings, the dynamism of the minerals knowledge economy generated the world's largest and most advanced national mining sector.

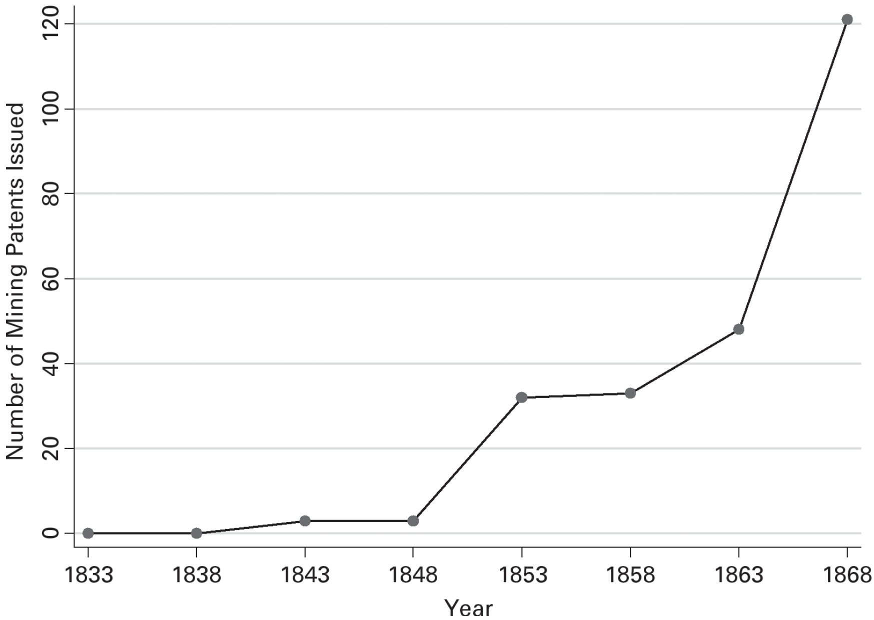
To some degree, intellectual property rights in mining technology could substitute for property rights in mineral-bearing lands. Indeed, figure 3.9 shows that the rate of patenting in mining accelerated at the time of the California gold rush and continued to rise thereafter. It is highly likely that the acceleration continued after 1870 as the training of mining engineers and metallurgists progressed, and mineral technology drew on increasingly advanced forms of knowledge. But intellectual property rights can hardly be a full resolution of the issue. As in modern times, patent claims were never fully secure because they were often objects of intense litigation and were vulnerable to technological obsolescence even if they were upheld. For these reasons, many new technologies were not patented but were protected instead by secrecy. Pearce's method for smelting refractory ores is but one example. Petra Moser's (2005; 2007) research on innovations displayed at nineteenth-century world's fairs suggests that less than half of them were patented, and mining had among the lowest industry patenting rates.

To be sure, American mining expanded within a larger society in which property rights and wealth accumulation were respected and protected. Under U.S. min-

[25] Goldin and Katz write that "something fundamental changed around the turn of the twentieth century," when "technological shocks" in scientific disciplines generated economically important findings that shocked the "knowledge industry" (1999, 38, 43, 51). A recent survey states that "the research university as we know it today did not emerge in the United States until around World War II" (Carlsson et al. 2009, 1197). On the founding of the AAU as a watershed, see Geiger (1986).

[26] Gerard (1998) shows that the rate of western mining claim disputes declined after 1900, suggesting that enforcement costs fell over time. There may be many reasons for this observation, but in any case, Gerard's evidence underscores the extremely high incidence of dispute during the period of U.S. ascendancy to world mining leadership.

FIGURE 3.9
Mining Patents by Five-Year Periods, 1835–1870



SOURCE: Compiled from a Google patent search of United States Patent and Trademark Office records for all patents using the terms "mine" or "mining" through 1870.

ing law, prospectors could acquire reasonably secure claims and legal title upon payment of modest fees. Claims could be sold and aggregated. Like patents on technology, mining claims were subject to nuisance suits and costly litigation. The promise of profit, however, was sufficient to attract large-scale capital into the sector from distant eastern and European investors. This was a thoroughly capitalist process from an early point. But it was a far cry from a standard account in which property owners invest willingly in improvements, secure in the knowledge that their asset values will capitalize the returns. Instead, the minerals knowledge economy was a complex institutional hybrid in which the prospect of large returns encouraged risky, long-distance private investments, with public and quasi-public support, assistance, and accommodation of various kinds. In short, it was much like a modern knowledge economy.

It would be imprudent to draw specific policy lessons from the U.S. experience for today's developing countries with mineral endowments. Engineering a gold rush to attract fortune seekers by the hundreds of thousands would be a challenge, and even if that were possible, one would hardly expect to kick-start a dynamic collective learning process as the result. The U.S. economy was already dynamic and innovative by the 1850s. The decentralized, endogenous, unregulated character of the episode reflected deep features of American society that are not readily transported across historical time and space. Perhaps the larger message is simply that property rights systems for natural resources should be appropriately adapted to specific cultural and historical contexts, rather than dictated by standardized formulas in isolation.

But one broad lesson does carry over from the American minerals experience, which is that minerals should not be understood as mere "endowments" given by nature, but as resources with potential for development. Realizing that potential requires investments of labor and capital, but above all, knowledge. And even in the modern globalized economy, in which the mineral sector draws on advanced frontiers of science-based technologies, useful forms of minerals knowledge still have strong geographically specific components. In general, the countries that have exploited their mineral potential successfully are those that have invested in indigenous, country-specific knowledge and human capital pertaining to exploration, extraction, processing, and sometimes usage of domestic resources. Because these learning processes have public-good properties, this sector deserves a legitimate place in the technology and engineering plans of developing countries with mineral potential.[27]

REFERENCES

Bakken, Gordon Morris. 1988. American mining law and the environment: The western experience. *Western Legal History* 1:211–236.

Barger, Harold, and Sam H. Schurr. 1944. *The mining industries, 1899–1939: A study of output, employment and productivity*. New York: NBER.

Barzel, Yoram. 1997. *Economic analysis of property rights*. 2nd ed. Cambridge, U.K.: Cambridge University Press.

Berry, Thomas Senior. 1984. *Early California: Gold, prices, trade*. Richmond, VA: Bostwick Press.

Blainey, Geoffrey. 1969. *The rush that never ended: A history of Australian mining*. 2nd ed. Melbourne: Melbourne University Press.

Bogue, Allan G. 1958. The Iowa claim clubs: Symbol and substance. *Mississippi Valley Historical Review* 45:231–253.

Carlsson, Bo, Zoltan J. Acs, David B. Audretsch, and Pontus Braunerhjelm. 2009. Knowledge creation, entrepreneurship, and economic growth: A historical review. *Industrial and Corporate Change* 18:1193–1229.

Christy, Samuel B. 1893. The rise of American mining schools and their relation to the mining industry. *Transactions of the American Institute of Mining Engineers* 23:444–465.

Church, John A. 1871. Mining schools in the United States. *North American Review* 112:62–81.

Clay, Karen. 2010. Natural resources and economic outcomes. In *Economic evolution and revolution in historical time*, eds. Paul Rhode, Joshua Rosenbloom, and David Weiman, 27–50. Stanford, CA: Stanford University Press.

Clay, Karen, and Randall Jones. 2008. Migrating to riches? Evidence from the California gold rush. *Journal of Economic History* 68:997–1027.

Clay, Karen, and Gavin Wright. 2005. Order without law? Property rights during the California gold rush. *Explorations in Economic History* 42:155–183.

David, Paul A., and Gavin Wright. 1997. Increasing returns and the genesis of American resource abundance. *Industrial and Corporate Change* 6:203–245.

Demsetz, Harold, 1967. Toward a theory of property rights. *American Economic Review* 57:347–359.

Ellickson, Robert C. 1991. *Order without law: How neighbors settle disputes*. Cambridge, MA: Harvard University Press.

Ellison, Joseph. 1926. The mineral land question in California, 1848–1866. *Southwestern Historical Quarterly* 30. Reprint. 1963. In *The public lands*, ed. Vernon Carstensen, 71–92. Madison: University of Wisconsin Press.

[27] These arguments are developed more fully in Clay (2010) and G. Wright and Czelusta (2006).

Engineering News. 1892. The engineering schools of the United States. XVII. The distribution of graduates. August 11: 139–140.

Fell, James E. 1979. *Ores to metals: The Rocky Mountain smelting industry*. Lincoln: University of Nebraska Press.

Geiger, Roger L. 1986. *To advance knowledge: The growth of American research universities, 1900–1940*. Oxford: Oxford University Press.

Gerard, David. 1998. The development of first-possession rules in U.S. mining, 1872–1920. *Resources Policy* 24:251–264.

———. 2001. Transaction costs and the value of mining claims. *Land Economics* 77:371–384.

Goldin, Claudia, and Lawrence F. Katz. 1999. The shaping of higher education: The formative years in the United States, 1890 to 1940. *Journal of Economic Perspectives* 13:37–62.

Halleck, Henry W. 1860. Introductory remarks by the translator. In *Fundamental Principles on the Law of Mines*, by J. H. N. de Fooz, i–cxlviii. San Francisco: J. B. Painter, printer.

Harvey, Charles, and Jon Press. 1989. Overseas investment and the professional advance of British metal mining engineers. *Economic History Review* 42:64–86.

Hendrickson, Walter B. 1961. Nineteenth-century state geological surveys: Early government support of science. *Isis* 52:357–371.

Hovis, Logan, and Jeremy Mouat. 1996. Miners, engineers, and the transformation of work in the western mining industry, 1880–1930. *Technology and Culture* 37:429–456.

Isenberg, Andrew C. 2005. *Mining California: An ecological history*. New York: Hill and Wang.

James, Ronald M. 1994. Defining the group: Nineteenth-century Cornish on the North American mining frontier. *Cornish Studies* 2:32–47.

Lasky, S. G. 1950. How tonnage and grade relations help predict ore reserves. *Engineering and Mining Journal* 151:81–85.

Leshy, John D. 1987. *The mining law: A study in perpetual motion*. Washington, DC: Resources for the Future.

Libecap, Gary D. 1978. *The evolution of private mineral rights: Nevada's Comstock Lode*. New York: Arno Press.

———. 1989. *Contracting for property rights*. Cambridge, U.K.: Cambridge University Press.

Lueck, Dean. 1995. The rule of first possession and the design of the law. *Journal of Law and Economics* 38:393–436.

———. 1998. First possession. In *The new Palgrave dictionary of economics and the law*. Volume 2, 132–144. New York: Stockton Press.

Manning, Thomas G. 1967. *Government in science: The U.S. Geological Survey, 1867–1894*. Lexington: University of Kentucky Press.

Mayer, Carl J., and George A. Riley. 1985. *Public domain, private dominion*. San Francisco: Sierra Club Books.

McDowell, Andrea. 2002. From commons to claims: Property rights in the California gold rush. *Yale Journal of Law and the Humanities* 14:1–72.

———. 2004. Real property, spontaneous order, and norms in the gold mines. *Law and Social Inquiry* 29:771–818.

The mineral industry: *Its statistics, technology and trade*. 1892–1905. New York: McGraw-Hill.

Miners and business men's directory. 1856. Tuolumne County, CA.

Monroe, Charles E. 1905. Precious metals recovered by cyanide processes. In *Special reports of the Census Office: Mines and quarries, 1902*, 591–645. Washington, DC: U.S. Government Printing Office.

Moser, Petra. 2005. How do patent laws influence innovation? Evidence from nineteenth-century world's fairs. *American Economic Review* 95:1214–1237.

———. 2007. Why don't inventors patent? National Bureau of Economic Research. Working Paper W13294.

Ochs, Kathleen. 1992. The rise of American mining engineers: A case study of the Colorado School of Mines. *Technology and Culture* 33:278–301.

Paul, Rodman. 1947. *California gold*. Cambridge, MA: Harvard University Press.

———. 1960. Colorado as a pioneer of science. *Mississippi Valley Historical Review* 47:34–50.

———. 1963. *Mining frontiers of the West, 1848–1880*. New York: Holt, Rinehart, and Winston.
———. 1966. *The California gold discovery*. Georgetown, CA: Talisman Press.
Pisani, Donald J. 1998/1999. "I am resolved not to interfere, but permit all to work freely": The gold rush and American resource law. *California History* 77:123–148.
Przeworski, Joanne Fox. 1980. *The decline of the copper industry in Chile and the entrance of North American capital, 1870–1916*. New York: Arno Press.
Read, Thomas Thornton. 1941. *The development of mineral industry education in the United States*. New York: American Institute of Mining and Metallurgical Engineers.
Richter, F. E. 1927. The copper-mining industry in the United States, 1845–1925. *Quarterly Journal of Economics* 41:236–291.
Rickard, T. A. 1932. *A history of American mining*. New York: McGraw-Hill.
Rowe, John. 1974. *The hard-rock men: Cornish immigrants and the North American mining frontier*. New York: Harper and Row.
Schmitz, Christopher. 1986. The rise of big business in the world copper industry, 1870–1930. *Economic History Review* 39:392–410.
Scott, Anthony. 2008. *The evolution of resource property rights*. Oxford: Oxford University Press.
Shavell, Steven. 2004. *Foundations of economic analysis of law*. Cambridge, MA: Belknap Press of Harvard University Press.
Shinn, Charles Howard. 1948 [1884]. *Mining camps: A study in frontier democracy*. New York: Alfred A. Knopf.
Smith, Grant H. 1998 [1943]. *The history of the Comstock Lode*. Reno: Nevada Bureau of Mines and Geology.
Spence, Clark C. 1970. *Mining engineers and the American West, 1849–1933*. New Haven, CT: Yale University Press.
Spude, Robert L. 1991. Cyanide and the flood of gold: Some Colorado beginnings of the cyanide process of gold extraction. *Essays and Monographs in Colorado History* 12:1–35.
State register and book of facts. 1857. San Francisco: Henry G. Langley and Samuel A. Mathews.
St. Clair, David. 1999. The gold rush and the beginnings of California industry. In *A golden state: Mining and economic development in gold rush California*, eds. James J. Rawls and Richard J. Orsi, 185–208. Berkeley: University of California Press.
Trimble, William J. 1914. *The mining advance into the inland empire*, 139–390. Madison: Bulletin of the University of Wisconsin.
Umbeck, John. 1981. *A theory of property rights, with application to the California gold rush*. Ames: Iowa State University Press.
U.S. Bureau of the Census. 1874. *Statistical atlas of the United States*. http://www.cartoko.com.
———. 1880. *Tenth census of the United States*. Vol. 14, *The United States Mining Laws and Regulations Thereunder, and State and Territorial Mining Laws, to which are appended Local Mining Rules and Regulations*. Washington DC: U.S. Government Printing Office.
U.S. Department of the Treasury. Bureau of Statistics. 1903. *Monthly summary of commerce and finance*. Washington DC: U.S. Government Printing Office.
Van Wagenen, Theodore. 1918. *International mining law*. New York: McGraw-Hill.
Wadsworth, M. E. 1997. Some Statistics of Engineering Education. *Transactions of the American Institute of Mining Engineers* 27:712–731.
Walton, Gary M., and Hugh Rockoff. 1998. *History of the American economy*. 8th ed. Fort Worth, TX: Dryden Press.
Williams, David. 1993. *The Georgia gold rush*. Columbia: University of South Carolina Press.
Wilson, Arthur J. 1992. *The professionals: The institution of mining and metallurgy, 1892–1992*. London: Institution of Mining and Metallurgy.
Woodward, Kathryn Morgan. 2009. Marvelous growth: Copper, technology and the firm, 1890–1913. M.S. thesis in economic and social history, Oxford University.
Wright, Doris M. 1940. The making of cosmopolitan California: An analysis of immigration, 1848–1870. *California Historical Society Quarterly* 19:323–343.

Wright, Gavin, and Jesse Czelusta. 2006. Resource-based growth past and present. In *Neither curse nor destiny: Natural resources and development,* eds. Daniel Lederman and William F. Maloney, 183–210. Stanford, CA: Stanford University Press and World Bank.
Wright, James E. 1966. *The Galena lead district: Federal policy and practice, 1824–1847.* Madison: State Historical Society of Wisconsin.
Yale, Gregory. 1867. *Legal titles to mining claims in California*. San Francisco: A. Roman.
Young, Otis E., Jr. 1982. The southern gold rush, 1828–36. *Journal of Southern History* 48:373–392.
Zerbe, Richard O., Jr., and Leigh Anderson. 2001. Culture and fairness in the development of institutions in the California gold fields. *Journal of Economic History* 61:114–143.