Volume Title: Learning by Doing in Markets, Firms, and Countries

Volume Author/Editor: Naomi R. Lamoreaux, Daniel M. G. Raff and Peter Temin, editors

Volume Publisher: University of Chicago Press

Volume ISBN: 0-226-46832-1

Volume URL: http://www.nber.org/books/lamo99-1

Publication Date: January 1999

Chapter Title: Patents, Engineering Professionals, and the Pipelines of Innovation: The Internalization of Technical Discovery by Nineteenth-Century American Railroads

Chapter Author: Steven Usselman

Chapter URL: http://www.nber.org/chapters/c10230

Chapter pages in book: (p. 61 - 102)

2 Patents, Engineering Professionals, and the Pipelines of Innovation: The Internalization of Technical Discovery by Nineteenth-Century American Railroads

Steven W. Usselman

What are the sources of technological change? Why and how do people create new techniques, and why and how do they or others choose to employ them? In designing the American patent system, the revolutionary generation provided answers to these deceptively simple questions. The founders conceived of innovation as occurring through a set of discrete exchanges in a market for novelty. A group of creators—we'll call them inventors—responds to incentives held forth by that market. The value of any particular novelty is set by the supply of alternatives and by the demand of consumers—many of whom are themselves producers—who draw upon the techniques available in the market for novelty in order to obtain perceived advantages. Government underwrites this market by providing temporary monopolies, without which the returns to invention would drop to zero and the incentive to innovate would evaporate. The patent system thus exhibits the same genius as the larger document of which it is a part: it provides a mechanism or structure that operates independently of the particulars involved.

But does that mechanism characterize all innovation? Does it apply equally well to all fields of technical knowledge, including those with highly organized communities of expertise focused on vast technical systems? And what happens as institutions such as corporations and trade associations alter market structures? In such circumstances can we detect alternative paths of innovation, and are those alternatives compatible with the mechanisms outlined in the patent system?

These questions are no mere abstractions. They are practical issues that first arose, perhaps not surprisingly, in the context of American railroading. This highly concentrated and technically sophisticated industry challenged the

Steven W. Usselman is associate professor of history in the School of History, Technology, and Society at the Georgia Institute of Technology.

patent system, as it did so many other areas of law, with unprecedented and unanticipated conditions. By the middle of the nineteenth century, claims by patent holders that conditions in the railroad industry interfered with the presumed free market exchange of patented inventions began to find sympathetic hearings in court. Convinced that inventors were not reaping a just return, several federal judges improvised a remedy known as the "doctrine of savings." This principle required infringers to compensate patent holders by paying three times the savings they had derived from using the invention, rather than merely three times the prevailing license fee. Railroads, suddenly exposed to far greater financial liabilities for patent infringement than they had ever anticipated, objected strenuously to the new doctrine. In one of the earliest examples of interfirm collective action, leading carriers formed trade associations to coordinate legal appeals and share the cost of litigation in key cases. As these disputes dragged on in court, not to be resolved fully until the 1880s, the associations carried the fight for relief from patent liability to Congress. Their proposed series of reforms to the patent laws attracted the attention of virtually everyone connected with the patent system and occupied both the House and Senate for critical weeks during successive terms in the late 1870s.

The doctrine of savings sparked such extraordinary measures not simply because it exposed railroads to significant financial liabilities in a few notable patent cases, but because it raised fundamental questions about the paths of technical change in the nineteenth-century American economy. In the eyes of railroads, the largest and most complex enterprises in that economy, the doctrine threatened to disrupt emerging conduits of innovation. For reasons having to do with the competitive structure of the industry and the evolving nature of its technology, railroads over the course of the nineteenth century increasingly sought to bypass the market for patented technologies. They hoped instead to internalize the process of technical discovery by incorporating it within a sustained, cooperative effort at steady improvement pursued by engineers and other salaried personnel employed by firms throughout the industry. Judges applying the doctrine of savings in effect called for railroads to pass the fruits of that widespread technical effort back to creative individuals, rather than permitting railroads to absorb the benefits of new techniques directly into the cost structures of transportation services. To no one's surprise, inventors supported the courts in this effort, but so too did many consumers of new technology who still viewed the patent system as an effective conduit of innovation in their industries.[1] Few areas of the economy had yet acquired the characteristics of railroading, and advocates of patent reform thus faced a daunting task in seeking changes in general statutes that would accommodate their special concerns while leaving the system intact.

1. As Naomi Lamoreaux and Kenneth Sokoloff (chap. 1 in this volume) suggest, consumers had good reason to believe the market for patented technologies had come to function as an especially effective conduit of innovation in the latter half of the nineteenth century.

In the end, Congress could not find a way to address conditions in the railroad industry without alienating the many inventors and innovators who saw no reason to disrupt the established rules governing patents, and the proposed reforms died in conference committee. Yet the story does not end there. Railroads ultimately found relief in the hands of a legal system that proved more capable than Congress of tailoring remedies to particular circumstances. Even with legislation still pending, railroad fury over the doctrine of savings subsided as the Supreme Court embraced a model of innovation that varied considerably from the form idealized by the patent system. In effect, justices accepted the arguments of American railroads that technical creativity in their industry typically resulted from the efforts of ordinary mechanics and engineers, not through discrete acts of patentable invention. The shifting legal climate at once legitimated customary practices by railroads regarding patents and new technology and provided them with incentives to internalize the process of technical discovery more thoroughly and more formally. By keeping closer watch over technical activities taking place in their own facilities and by utilizing patent associations and various technical and engineering societies to exchange information about new technology, railroads monitored technical progress in ways that enabled them to find favor in a justice system increasingly sympathetic to the idea that much innovation originated and diffused through channels independent of the patent system.

This paper examines that internalization of discovery by American railroads and reflects upon its broader significance for our understanding of technical innovation in the emergent corporate economy of nineteenth-century America. It begins by tracing the competitive forces and technical factors that prompted railroads by midcentury to take a proactive role in the process of technical change. Under these conditions railroads and inventors alike had good reason to suspect that the model of innovation presumed under the patent system did not correspond to the actual conditions prevailing in the railroad industry. A close look at the cases that prompted railroads to pursue patent reform reveals the extent of the discrepancy and the enormity of the stakes involved. After discussing the patent cases in some detail, the paper describes the ways in which railroads further internalized the process of technical change in light of the shifting legal climate. In order to situate those developments more broadly, the paper then introduces a dual-pipeline schematic of innovation flows and discusses its relevance to railroads and to the economy as a whole. A brief comparative conclusion suggests that, though the passage from inventive marketplace to administered innovation may have set railroads apart from most other businesses during the nineteenth century, the internalization of technical change in the railroad industry may have anticipated similar developments in other systems-based industries of a later day.

2.1 Insider Innovation: Patterns of Change in Early Railroad Technology

What, then, were the particular circumstances that brought railroads into conflict with the patent system? More specifically, why by the third quarter of the nineteenth century did so many informed observers agree that the railroad industry did not facilitate the exchanges of technical novelties necessary to establish a market value of a patented innovation?

To some extent, the answers to these questions must be traced back to the earliest days of the railroad industry and to the nature of the competition it fostered. American railroading began as a series of localized experiments with an unproven technology of revolutionary potential. During their early decades, most railroads enjoyed a local monopoly in the market for railroad services. They functioned as semipublic ventures whose purpose was not so much to race westward to a common destination and compete for the same pool of traffic as other lines, but to build an infrastructure that would lure capital and human resources away from other locales. The vastness of the North American landscape helped sustain this developmental function for many decades.[2]

In some respects this pool of isolated enterprises constituted an ideal market for enterprising inventors. The records of the patent office reveal that railroads accounted for a disproportionate share of patents during the antebellum period. Every year the list of new patents published in the annual report of the commissioner of patents contained more and more devices under the headings "Civil Engineering and Architecture" and "Land Conveyance." Most of these pertained to railroads. Between 1852 and 1865 the number of patents granted for inventions pertaining directly to railroads increased from about 50 to over 500 per year.[3] Some inventions, such as the Howe truss and the Westinghouse air brake (patented in 1869), earned their creators renown and some fortune.

Some evidence suggests, moreover, that patentees and railroads engaged in market transactions very much like those we would envision under the patent

2. This paragraph and many of my subsequent generalizations about technological innovation in the railroad industry lean heavily on my forthcoming study, "Regulating Innovation: The Business and Politics of Technical Change on American Railroads, 1846–1916." Some of the material in this study appeared originally in "Running the Machine: The Management of Technical Change on American Railroads, 1860–1910" (Ph.D. diss., University of Delaware, 1985). The literature on early railroad development in the United States is vast. For a recent treatment, see Colleen A. Dunlavy, *Politics and Industrialization: Early Railroads in the United States and Prussia* (Princeton: Princeton University Press, 1994).

3. Statistics on patents come from reports of the commissioner of patents, which appear annually in the collected documents of the U.S. House of Representatives and the U.S. Senate. For the years discussed here, these reports contain only sketchy information on the number of patents granted for railroad inventions. The commissioner provided itemized tabulations of patents sporadically, and the categories used often did not identify clearly those patents that served the railroads. The figure cited for 1852 comes from the "Report of the Commissioner of Patents for 1852," U.S. Senate, 32d Cong., 2d sess., Executive Document 55, p. 438. That for 1865 appears in the "Report of the Commissioner of Patents for 1865," U.S. House of Representatives, 39th Cong., 1st sess., Executive Document 52, p. 18.

system. Circulars describing patented devices flowed into the offices of railroad executives, and at least some managers paid them serious attention. Robert Harris, chief operating officer of the Chicago, Burlington, and Quincy during the 1860s and much of the 1870s, regularly passed the circulars on to his subordinates and solicited their opinions. An admitted enthusiast for new technology, Harris corresponded frequently with inventors.[4] In addition to providing testimonials for their advertisements, Harris sometimes offered hints about how best to promote an invention he particularly liked, such as the Miller platform.[5] When Burlington employees wrote to their chief about an idea, he gave them a considered judgment on its technical merits and coached them on marketing strategies, including patents. On two occasions during the early 1870s, Harris personally set inventors up in the Burlington's facilities and encouraged them to develop patentable inventions.[6] Once, in a fit of exasperation caused by one insistent inventor, Harris scrawled to a subordinate, "Patents and passes will be the death of me!"[7] This was no idle complaint; Harris did devote much of his energies to the subject. Perhaps not surprisingly, he would come to play a major role in railroad efforts to reform the patent system.

No other top executive left behind a record of such thorough involvement with patents as Harris, but many of his contemporaries at other lines certainly gave the subject close attention. The board of directors at the Pennsylvania Railroad frequently considered questions pertaining to innovation, and its Committee on Supplies negotiated licensing agreements with several inventors.[8] The Pennsylvania's famed president, J. Edgar Thomson, personally investigated new technologies such as steel rails and negotiated contracts with individuals such as George Westinghouse, inventor of the air brake.[9] Thomson's counterpart at the rival Baltimore and Ohio, John Work Garrett, seldom exhibited the same perceptive attention to technical detail (much to the detri-

4. Robert Harris's letterbooks and many other of his papers can be found in the papers of the Chicago, Burlington, and Quincy Railroad at the Newberry Library in Chicago (hereafter, CBQ Papers). Much of his correspondence pertaining to inventions can be found in the subject file 33 1870 2.5. On one occasion, Harris advised an inventor not to rest his hopes on the testimonial "of one who is known to be so ready to entertain novelties as I am" (R. Harris to J. A. Sleeper, 8 August 1872, CBQ Papers, 3H4.1, 28:116–18.

5. Harris to W. W. Wilcox, 18 October 1867, 11:22; to Col. Miller, 2 May 1868, and 7 May 1868, 12:302, 327; to J. F. Joy, 11 May 1868, 12:338–340; to Thomas Swingard, 22 March 1869, 15:259; to P. S. Henning, 4 June 1869, 16:239; to Col. C. G. Hammond, 15 November 1869, 18:92; to C. E. Perkins, 16 November 1869, 18:104–7; all in CBQ Papers, 3H4.1.

6. R. Harris to F. H. Tubbs, 17 June 1868, and 1 June 1870, CBQ Papers, 3H4.1, 12:501, 20:287–88; to W. W. Wilcox, 7 May 1869, CBQ Papers, 3H4.1, 16:38; to J. Q. A. Bean, 20 June 1870, CBQ Papers, 3H4.1, 20:378.

7. R. Harris to Mr. Hitchcock, 23 December 1868, CBQ Papers, 3H4.1.

8. Pennsylvania Railroad, Minutes of the Committee on Supplies, accompanying Minutes of the Meetings of the Board of Directors. These are available at the Hagley Museum and Library, Wilmington, DE, Acc. 1807 (hereafter Board Papers, PRR Papers).

9. On steel rails, see *Annual Report of the Pennsylvania Railroad* 17 (1863): 13–14, and 20 (1866): 26–27, 63–64. On air brakes, see Minutes of the Meeting of the Road Committee, 22 December 1869, 12 January 1870, 21 January 1870, 9 February 1870; David H. Williams to J. Edgar Thomson, 12 December 1869, all in Board Papers, PRR Papers.

ment of his company), but Garrett and his personal assistant maintained active correspondences on technical affairs and patents.[10] Top management at another eastern railroad, the Philadelphia and Reading, followed an arrangement typical of many lines. They trusted almost all technical questions to a single individual, master mechanic John E. Wootten, who monitored railroad technology and patents with a verve that surpassed even that of Harris at the Burlington.[11] At most railroads, it seems, the development and acquisition of new technology formed a routine subject of discussion in the highest echelons of management. Frequently, the discussion involved patents.

Yet even in this early period, some features of the railroad industry tended to work against the model of technical change embedded in the patent system. Because railroads operated their own machine shops and foundries for purposes of maintenance and repair, they often possessed skills that enabled them to develop their own solutions to technical problems. Individuals such as Wootten considered it something of a badge of honor that he could devise his own solutions to any technical challenge.[12] As an institution, the Pennsylvania Railroad exhibited a similar bravado, with considerable justification. Roads such as the Burlington, itself much admired among western roads for its technical competence, routinely looked to the Pennsylvania for guidance on technical matters.[13] In 1867, to cite one example of the Pennsylvania's attitude, the railroad had one of its mechanics investigate ways of ventilating cars, a problem that had long attracted the attention of many inventors. The mechanic concluded that given six months' time the Pennsylvania could develop a better ventilator than any then available.[14] Other railroads acted similarly. When the Baltimore and Ohio grew irritated at paying a supplier for its journal boxes, it asked one of its own mechanics to devise an alternative. Within weeks, the railroad had negotiated a much more favorable agreement with the supplier.[15] As these examples suggest, inventors and suppliers of railroad technology operated in a world of extraordinarily well-educated customers who could easily fend for themselves if provoked.

The personnel who worked in the railroad shops, as well as the engineers

10. See especially the Patents and Inventions File in the archives of the Baltimore and Ohio Railroad, MS 1925, Maryland Historical Society, Baltimore (hereafter B&O Papers); the letters of John Work Garrett, MS 2003, Maryland Historical Society (hereafter Garrett Papers).

11. Wootten's letters are in the archives of the Philadelphia and Reading Railroad, Hagley Museum and Library, Wilmington, DE, Acc. 1451 (hereafter Reading Papers).

12. Letterbooks of John E. Wootten, Reading Papers. See also James L. Holton, "John Wootten: Locomotive Pioneer," *Historical Review of Berks County* (summer 1978): 97–107.

13. When discussing technology, managers at the Burlington frequently inquired about practices on the Pennsylvania, and on several occasions they referred outside inventors to that line. By the same token, lines to the west of Chicago frequently consulted the Burlington on technical matters. See CBQ Papers.

14. Minutes of the Meetings of the Board of Directors, 18 April 1866, 5:47; 2 May 1866, 5:50; 19 April 1866, 5:67; 6 March 1867, 5:108, Board Papers, PRR Papers.

15. Patents and Invention File, B&O Papers, contains many letters pertaining to the innovation, known as the Lightner journal box. J. C. Davis to John King, Jr., n.d., provides a useful summary of the case.

who operated the locomotives, occupied an ambiguous position between employee and independent expert. Sometimes railroads encouraged these men to patent devices; other times they expressed the idea that modification and experiment were essential parts of the job. In 1850 James Millholland, master mechanic at the Philadelphia and Reading prior to Wootten, received $1,000 from his employer in payment for rights to all of his inventions. But by no means had this become a standard condition of employment at the Reading or elsewhere in the industry.[16] Robert Harris of the Burlington told a mechanic who asked for compensation that "one in the employ of a railroad company has no rightful claim upon that company for a patent fee upon an article introduced or invented in the prosecution of his ordinary duties," and that "to the performance of the duties of any position one's best efforts and ingenuity should be given."[17] Harris's bark, however, proved louder than his bite. He later awarded the mechanic $350, and on occasion paid similar premiums to other creative employees. In general, Harris seems to have assumed a gentleman's agreement would prevail in such circumstances, with the railroad paying for the patent application and the inventor granting his employer unlimited use of the device. When his successor, Charles Perkins, neglected to pay the fees for one employee, a close subordinate corrected the oversight and told Perkins that "our practice in this matter has been uniform for a number of years back, and several patents have been taken out under it."[18]

The nature of competition in the railroad industry further blurred distinctions between producers and consumers of railroad technology. Because railroads during their early lives did not see themselves as being engaged in direct competition with one another over technical performance, they saw little purpose in monopolizing a technique developed in-house. Sensing that in this experimental stage they had more to gain by openness than secrecy, railroads generally exchanged technical information quite freely. The various lines operated almost as a set of concurrent experiments taking place in a number of different laboratories, with managers applying the same basic technique to a variety of conditions and discovering innumerable useful adaptations in the process.

The developmental function of railroad enterprise during this formative period could also draw railroads into unusually close relationships with suppliers. As providers of an essential utility, railroads seldom restricted their business transactions with suppliers to the purchase of a commodity. The two parties also exchanged transportation services and traffic volume. In many cases, moreover, railroads provided capital to their suppliers. These sorts of exchanges were embedded within the development policies of the railroads, and they often dovetailed comfortably with the personal interests of managers.

16. Managers Minutes, 15 March 1850, Board of Directors Minute Book, book C, p. 9, Reading Papers.

17. R. Harris to C. M. Higginson, 6 November 1875, CBQ Papers, 3H4.1.

18. Henry B. Strong to C. E. Perkins, 1 November 1888, CBQ Papers, 3P4.57.

Andrew Carnegie and his fellow officers at the Pennsylvania made fortunes by investing in supply firms with which the Pennsylvania did business.[19] The Baldwin Locomotive Works, located near the Pennsylvania's main offices on Broad Street in Philadelphia, rose to prominence when a loose consortium of lines with ties to the Pennsylvania funneled large orders and vital working capital its way.[20] One cannot begin to comprehend the operations of the nineteenth-century steel industry without taking such factors into account.[21]

These unusual characteristics of relations between railroads and suppliers of technology, combined with the special nature of railroad technology and the distinctive aspects of competition among railroads, produced an environment in which innovation can hardly be described as flowing from free competition among inventors seeking to meet the demands of a broad market. Rather, the process of technical discovery might best be characterized, to borrow a phrase from Naomi Lamoreaux, as "Insider Innovation."[22] Information about railroad technology flowed among a network of interested and unequal parties whose perspectives and decisions regarding technical innovations involved a complex mix of motives. Though the railroad industry fostered a climate of experiment and trial that put new technologies through a rigorous market test, success often came to those with advantages that went beyond mere technical accomplishment.

The essential medium of exchange in this complex network of exchange was the patent license. Virtually all railroads preferred to obtain licenses rather than buying patented products on the open market. The Pennsylvania, especially, exhibited this tendency early and pursued it relentlessly, and other railroads followed suit.[23] Licenses enabled railroads to take advantage of the manufacturing abilities of their own shops and those of the major shops and foundries along their lines with whom they subcontracted. More important, they helped railroads absorb new techniques into the pool of inside knowledge that resided within those technical facilities. Railroads clearly expected that techniques covered by licenses would soon be modified in ways that rendered them generic. Only by retaining exclusive control of their patents and integrating for-

19. Harold C. Livesay, *Andrew Carnegie and the Rise of Big Business* (Boston: Little, Brown, 1975), 45–75.

20. John K. Brown, *The Baldwin Locomotive Works, 1831–1915: A Study in American Industrial Practice* (Baltimore: Johns Hopkins University Press, 1995).

21. Elting E. Morison, *Men, Machines, and Modern Times* (Cambridge: MIT Press, 1966), 123–205; Usselman, "Running the Machine," 81–133; Glenn Porter and Harold C. Livesay, *Merchants and Manufacturers: Studies in the Changing Structure of Nineteenth Century Manufacturing* (Baltimore: Johns Hopkins University Press, 1971), 79–115, 131–53; Thomas J. Misa, *A Nation of Steel* (Baltimore: Johns Hopkins University Press, 1995).

22. The phrase comes from her recent study, *Insider Lending: Banks, Personal Connections, and Economic Development in Industrial New England* (Cambridge: Cambridge University Press, 1996), which emphasizes the importance of kinship ties and other close relations in the early-nineteenth-century economy.

23. Minutes of the Meetings of the Board of Directors and Associated Reports, Board Papers, PRR Papers.

ward into production could inventors avoid that fate. So great was the desire to internalize new techniques that the Pennsylvania even pressed to obtain a license from George Westinghouse, an inventor who had located his manufacturing facilities along its tracks and who had received funding from several of the railroad's Pittsburgh executives.[24]

The ultimate intent of railroads was apparent as well in their willingness to forgo paying any fee and to risk infringement. Latecomers to an innovation were especially prone to flaunt claims of patentees. This behavior derived in part from trends in price. Though they might debate whether the phenomenon resulted from trial discounts granted at the beginning of the monopoly period or from extortionist rates demanded later on, most people involved with railroad technology agreed that license fees increased during the life of a patent.[25] Higher prices of course discouraged payment in their own right. Perhaps more importantly, they increased the effective penalty for infringement, because courts awarded damages totaling three times the amount a patent holder would have earned from the established license fee. Instead of paying an inflated fee, railroads would infringe and claim the lower fee as the established one if taken to court. With each passing year in a patent's life, moreover, the possibility arose that another patent covering a similar principle would come to light. If this happened, railroads stopped paying fees and left the inventors to battle over the question of priority. This practice had become so routine by 1872 that Harris told an employee who had invented a new grain door, "You should buy [another inventor] out before selling your door to other railroads; otherwise, with two claims, roads will use doors and pay for neither."[26]

2.2 Outside Liabilities: The Doctrine of Savings and Patent Law

Robert Harris's advice to inventors attains a heightened significance when considered in light of a series of important legal cases pending at the time in the federal courts. The cases involved a new legal doctrine known as the doctrine of savings. Articulated by judges in a series of cases involving railroads, this doctrine established a novel method of assessing damages for infringement. Traditionally, courts had arrived at a damage figure by determining the profits patent holders made through sales of their inventions to consumers who had not infringed. Those convicted of infringement paid three times the profits lost. (In situations where the patent holder sold licenses instead of finished

24. Minutes of the Meeting of the Road Committee, 22 December 1869, 12 January 1870, 21 January 1870, 9 February 1870; George Westinghouse, Jr., to D. H. Williams, 13 November 1869; David H. Williams to J. Edgar Thomson, 12 December 1869; all in Board Papers, PRR Papers.

25. U.S. Senate, "Arguments before the Committees on Patents of the Senate and the House of Representatives in Support of and Suggesting Amendments to Bills (S. 300 and H.R. 1612) to Amend the Statutes in Relation to Patents, and for Other Purposes," 45th Cong., 2d sess., Miscellaneous Document no. 50.

26. Robert Harris to Bassler, 4 April 1872, CBQ Papers, 3H4.1, 26:498.

products, damages totaled three times the established license fee.) This method of assessing damages presumed that enough transactions had taken place to establish a market price for either the patented item or the license. Over time, however, several patent holders convinced the courts that in industries such as railroading the market never established a fair value for an invention. Because they possessed extensive technical expertise in their repair facilities and could generally manufacture and refine any new technology, railroads almost always preferred to obtain licenses rather than purchase patented devices. With a few firms controlling the bulk of the mileage, the market did not have sufficient consumers to establish a fair price for the license. A few railroads bought licenses (often at a discount before a device had proven its worth), then others infringed, figuring they would at worst pay three times an artificially discounted price. Once courts accepted this argument, as they had good reason to do, judges searched for alternative means of calculating damages. They settled on asking infringers to pay three times the savings they had obtained by employing the patented technology.[27]

The doctrine of savings posed a severe threat to railroads. Under the doctrine their cavalier practices regarding licenses could be turned back against them with damages far greater than they had ever imagined. The threat was all the more alarming because, by dealing with innovators on an ad hoc basis, railroad managers had never defined a coherent set of patent policies. Until 1872, for example, Harris did not even maintain a centralized list of all licensing agreements.[28] Such lax procedures had served the railroads well under the regime of insider innovation. Now, under the doctrine of savings, they left railroads exposed to vast liabilities and threatened to disrupt permanently the established routines of technical discovery.

As railroads wasted no time in pointing out, the doctrine of savings left much to be desired. On a strictly practical level it asked courts to account for a firm's costs more closely than many firms could themselves. But railroads also objected on more philosophical grounds. The doctrine presumed that the economic benefits of new technologies resulted entirely from the inventive act and not at all from the innovative efforts of the companies that employed them. Even the best accounting of savings, moreover, failed to account for benefits such as improved safety and comfort, whose value could not easily be expressed in terms of expenses saved. Yet for all its limitations, the doctrine of savings marked a serious and carefully reasoned effort by the judicial system to take a system of patent law that had been conceived for a market economy

27. In addition to U.S. Senate, "Arguments before the Committees on Patents," this summary and my subsequent discussion of cases and legislation involving the doctrine of savings is based largely on U.S. House of Representatives, "Report of the Committee on Patents," 2 March 1875, 43d Cong., 2d sess., Rept. 274; and U.S. Senate, "Reports of the Committee on Patents," 4 February 1873, 42d Cong., 3d sess., Rept. 369; 2 June 1874, 43d Cong., 1st sess., Rept. 471; 5 March 1878, 45th Cong., 2d sess., Rept. 116.

28. A list of licenses, prepared at Harris's request when he discovered the lapse, can be found in the CBQ Papers, f32.4.

and apply it to an environment characterized by limited or nonexistent markets. Railroads would find it very difficult to overcome.

Of the several cases that led to the doctrine of savings, by far the most important involved two patents covering "double-acting" brakes for railroad cars. Holders of these patents, which were initially issued in the early 1850s and were reissued by Congress two decades later, claimed that the devices had saved railroads substantial sums in wages by enabling brakeman to set two brakes at once. In one case, known as the Stevens patent, the Supreme Court twice concurred. Following its favorable decisions in 1868 and 1882, owners of the patent secured settlements with many railroads for $25 per car for each year of infringement.[29] Liabilities in the second case, known as the Tanner patent, threatened to run considerably higher. In the early 1870s, federal courts in Illinois twice affixed damages of several hundred dollars per car for each year of service.[30]

Railroads sought to counter these rulings through coordinated action. Early in 1867 the major Chicago roads and other western lines agreed to join the Western Railroad Association (WRA), which would conduct common defenses in patent suits and monitor all issues relating to patents in the industry.[31] About a dozen major eastern roads agreed to form an identical organization the same year.[32] Lines would pay annual fees, assessed in proportion to earnings, and in return receive full legal services, including consultation on the legal status of all inventions. The railroad patent associations thus constituted

29. James R. Doolittle to J. W. Garrett, 16 May 1870, B&O Papers. The Baltimore and Ohio balked at these terms and conducted its own suit against the Stevens claim, but in 1882 the Supreme Court again ruled against the railroads. At that point the Western Railroad Association advised the Pennsylvania to settle for a fixed fee of $25,000 (George Harding to Wayne McVeagh, 4 December 1882; A. McCallum to Hon. James A. Logan, 3 January 1883; John Scott to Geo. Roberts, 9 January 1883; all in Board Papers, PRR Papers).

30. The first judgment, based on savings in wheel wear as well as brakemen's wages, assessed damages at $455 per car per year. They totaled nearly $64,000 on the Chicago and North Western Railroad alone. Other lines had incurred substantially larger liability. Two years later the court reduced the allowance for wheel wear, but damages remained over $300 per car per year (*Railway Company v. Sayles, U.S. Reports,* 97 [October 1878]: 556–57; U.S. House of Representatives, "Report of the Committee on Patents").

31. U.S. Senate, "Arguments before the Committees on Patents," 191–92.

32. Isaac Hinckley to J. W. Garrett, 1 April 1867, Garrett Papers, box 86, subject 9614; John J. Harrower, *History of the Eastern Railroad Association* (Eastern Railroad Association, 1905), 22–30. Some plans for the two associations were laid in October 1866 at the meeting of the National Railway Convention, whose proceedings of May 1867 reported that constitutions for the proposed organizations were still being circulated among prospective members. Those proceedings noted that in early 1866 New England railroads had organized for common defense in a suit involving the brake patent of C. B. Turner. Impetus for the associations came from the brake cases, and the efforts under way to create a national organization devoted to railroad interests certainly contributed to their rapid formulation (*Proceedings of the National Railroad Convention* [New York, 1867], 20–22). I am indebted to Professor Colleen Dunlavy of the University of Wisconsin for this reference. On the efforts to form national railroad organizations, see Dunlavy, *Politics and Industrialization,* chap. 4 (145–201); Colleen A. Dunlavy, "Organizing Railroad Interests: The Creation of National Railroad Associations in the United States and Prussia," *Business and Economic History,* 2d series, 19 (1990): 133–42.

an effort to formalize and preserve the internalization of technical discovery that had always been a significant component of innovation in the industry.

The key to the associations was collective, unified action. Members agreed to provide any information regarding disputed technologies and to inform the associations of inventions developed in their own shops. Such knowledge would help lawyers prepare their appeals. More importantly, railroads hoped to prevent patent holders in the future from quietly negotiating agreements with a few lines, then later using those agreements to gain legitimacy in the eyes of the courts and extract large settlements from other lines that had accumulated significant liabilities under the doctrine of savings. Any member who reached a settlement with an individual currently bringing suit against another member would sacrifice its rights to defense by the association.[33]

As association lawyers prepared their appeals to the Supreme Court, the nervous railroads quietly approached their friends on the congressional judiciary committees with proposals to reform the patent laws. To their delight, association lobbyists found themselves in the unlikely company of the Grangers, whose farm constituency had been plagued by lawsuits claiming infringement of patents for the driven well (basically, a pipe sunk in the ground until it tapped water) and the swing gate (a common device used to sort livestock and keep it penned). Unable to travel to federal courts to meet the accusations, outraged farmers had petitioned Congress for relief. Decrying the patent system as yet another conspiracy between capitalists and government to create exploitative monopoly power, the petitioners asked to be exempted from liability under so-called innocent-purchaser provisions. (If such provisions became law, one skeptical Congressman later quipped, the best patent adviser would be the one who knew the least.) The revisions supported by the railroads appeared temperate in comparison yet still moved the patent laws toward the goals Grangers desired. The bill sailed through committee and onto the floor of both houses. Only the last-minute intervention of powerful New York senator Roscoe Conkling, who revealed the backroom machinations of the railroads, scuttled the proposed reforms.[34]

Patent reform remained a hot issue when Congress reconvened. Now, however, the proposed changes would have to pass through the standing committees on patents. In the Senate, this committee was dominated by liberal Republican and mugwump New Englanders who practiced law in the federal courts at Boston, which because of the preponderance of patents granted in the region were generally regarded as the most sophisticated and influential venue for patent litigation in the country. These men treated the patent system with the sense of benevolent stewardship that characterized their approach to most political issues. (Their chair was a New Hampshirite by the name of Bainbridge

33. Eastern Railroad Association, "Constitution," 6 February 1867, copy in Garrett Papers, box 86, subject 9614. On the assessment of fees, see also Harrower, *History*, 31.

34. This brief summary of the efforts to reform the patent law is based on U.S. Senate, "Arguments before the Committees on Patents"; U.S. Senate, "Reports of the Committee on Patents"; and a thorough reading of the *Congressional Record* for the period of debate, 1876–84.

Wadleigh.) With reverential tones they guarded it from radical reforms such as those proposed by the Grangers, while claiming for themselves the responsibility of adjusting the patent laws in light of the serious concerns raised by railroads. Fearful that the amendments proposed by railroads themselves would gut the system, they sought to orchestrate a compromise. They proposed implementing a statute of limitations on lawsuits and requiring patent holders to renew their rights every few years or forfeit the right to sue. Most importantly for railroads, committee members acknowledged the difficulty of accounting for the savings derived from new techniques and called for courts to focus instead on establishing an appropriate license fee.[35]

As befit its stewardship role, the committee proceeded in a highly deliberate and open fashion. It invited patent experts representing a variety of manufacturing interests to testify at hearings on the bill, including those from the shoe industry who bought patented equipment and those from the machining firms who supplied them, and distributed published transcripts widely. When the bill at last came before the full Senate in December 1878, Wadleigh presented it as a technical measure requiring little debate. But the Senate refused to entrust the experts. To the chagrin of the moderate reformers, westerners immediately resumed the call for innocent-purchaser provisions, while Conkling and his allies again denigrated the bill as the handiwork of railroads. Astoundingly, the debate stretched on for weeks, occupying much of the brief but critical lame-duck session which for Republicans marked a last gasp before they relinquished their eighteen-year stranglehold on the House and Senate. The measures eventually passed, but not in time for conference with the House, which had approved a more radical set of reforms. Responsibility for reforming the patent system would remain with the courts.[36]

There, the railroads finally found relief. In October 1878, with the patent legislation pending and the Senate debate still two months away, the Supreme Court at last handed down its decision in the Tanner case. Rather than confront the issue of the doctrine of savings directly, the justices based their decision on WRA and Eastern Railroad Association arguments that the railroads had easily found alternatives to the Tanner method of linking the brakes. Some lines, they claimed, had tried out several arrangements for linking brakes on an experimental basis prior to the time Tanner obtained his patent. These experiments, in the opinion of the railroads, demonstrated that the idea of linking brakes was "in the air" at the time and thus did not deserve broad coverage in a patent. The court agreed. Though the experimental devices were "not so perfect as that of [Tanner]" and though railroads had never actually patented them, noted

35. This characterization of the Senate Committee on Patents is based primarily upon U.S. Senate, "Report of the Committee on Patents," 5 March 1878, 45th Cong., 2d sess., Rept. 116; on profiles obtained from standard congressional biographical references; and on coverage and editorials pertaining to the political dispute in the *New York Times*, *Scientific American*, and other periodicals.

36. This brief summary of the legislative debate is based on a close reading of the *Congressional Record.*

the justices in reversing a series of rulings by lower courts, their use invalidated Tanner's claim to have achieved a basic principle. "Like almost all other inventions," confidently wrote Justice Bradley of an innovation that had occurred three decades earlier, "that of double brakes came when, in the progress of mechanical improvement, it was needed; and being sought by many minds, it is not wonderful that it was developed in different and independent forms." Expressing a philosophy of technical change in which the railroads and others who employed patented technologies could find great comfort, he continued, "[I]f the advance towards the thing desired is gradual, and proceeds step by step, so that no one can claim the complete whole, then each is entitled only to the specific form of device which he produces.[37]

As Bradley's telling reference to "almost all other inventions" suggests, this ruling held a significance far beyond the case of double-acting brakes. A few years later, the justices elaborated on the theory of innovation they had advanced in the Tanner case.

> The process of development in manufactures creates a constant demand for new appliances, which the skill of the ordinary head-workmen and engineers is generally adequate to devise, and which, indeed, are the natural and proper outgrowth of such development. Each step forward prepares the way for the next, and each is usually taken by spontaneous trials in a hundred different places. To grant a single party a monopoly of every slight advance made, except where the exercise of invention somewhat above ordinary mechanical or engineering skill is distinctly shown, is unjust in principle and injurious in its consequences. . . .
>
> It was never the object of [the patent] laws to grant a monopoly for every trifling device, every shadow of a shade of an idea, which would naturally and spontaneously occur to any skilled mechanic or operator in the ordinary progress of manufacturers. Such an indiscriminate creation of exclusive privileges tends rather to obstruct than to stimulate invention.
>
> It creates a class of speculative schemers, who make it their business to watch the advancing wave of improvement and gather its foam in the form of patented monopolies, which enable them to lay a heavy tax upon the industry of the country without contributing anything to the real advancement of the art. It embarrasses the honest pursuit of business with fears and apprehensions of concealed liens and unknown liabilities to law suits and vexatious accountings for profits made in good faith.[38]

With this rationale the Supreme Court effectively sanctioned the sorts of legal arguments that the railroad associations would almost always be capable of advancing. With access to nearly all companies and with individual firms taking great care to document their technical activities, the lawyers at the ERA and the WRA could readily establish precedence and undermine broad claims

37. *Railway Co. v. Sayles, U.S. Reports* 97 (October 1878): 556–57.

38. The case was *Atlantic Works v. Brady,* decided 5 March 1883, and quoted in *Annual Report of the Executive Committee of the Eastern Railroad Association* 19 (1885): 16 (hereafter *ERA Annual Reports*).

pertaining to virtually any aspect of technology.[39] Since courts retained the right to review questions pertaining to originality at every stage of appeal, the railroads stood an excellent chance of escaping liability at some point in the judicial process. With courts willing to consider techniques that had not been patented as evidence of priority, moreover, the associations or their members would not have to take out patents themselves in order to accomplish their goal. (Though as a precaution they often did so, making sure that the individuals holding the rights turned them over to an association member.) Railroads needed only to pool information and to keep a united front in their dealings with patent holders.[40]

Perhaps the surest testimony to the effectiveness of the patent associations—and to the diminished importance of patented devices—was in the reduced frequency of litigation. "During the last three years," reported the secretary of the ERA in 1887, "only four suits for infringement of patents have been brought against our members," and all but one was "unimportant, commenced by the patentees themselves, and of a local nature.[41] Frustrated inventors, unable or unwilling to pursue their claims individually, channeled their fight into collective assaults on the associations themselves. In a rare display of concerted action, they banded together under the auspices of the Inventors Protective Agency, which lobbied Congress and sued the patent associations for restraint of trade.[42] But these efforts went for naught. Courts upheld the rights of railroads to combine in their defenses in patent cases, and Congress twice rejected petitions that would have declared the ERA and WRA in violation of the antitrust laws.[43]

Ironically, the biggest threat to the associations came ultimately from their own success. With virtually no litigation afoot, some railroad executives began to question their utility. Association secretaries, in a classic illustration of the bureaucratic propensity for self-preservation, subtly began to redefine their mission. Newsletters and reports increasingly provided advice of a narrowly technical nature, with little or no reference to legal issues.[44] One WRA secre-

39. By 1876 the WRA already included eighty-one lines operating 32,000 miles of track (U.S. Senate, "Arguments before the Committees on Patents," 191–92). Within a year of the Tanner decision, nearly every major line in the east belonged to the ERA (Isaac Hinckley to J. W. Garrett, 24 July 1879, Garrett Papers, box 86, subject 9614).

40. In 1878 the ERA amended its constitution to provide stronger sanctions against firms that negotiated their own agreements with holders of disputed patents. The secretary of the association complained that such deals lent credence to the claims of inventors and hurt the chances for success in court. "To obtain the best results," he cautioned, "the members of the Association must act as a unit, and it is believed that this unity of action has been the true cause of our success heretofore" (*ERA Annual Report* 12 [1878–79]: 8–9).

41. *ERA Annual Report* 21 (1887): 26.

42. *New York Times*, 21 October 1883, 3; 23 October 1883, 8; 24 October 1883, 4.

43. *ERA Annual Reports; New York Times*, 8 May 1892, 20; *Scientific American* 3 May 1890, 176; 12 March 1892, 160–61; William K. Tubman, *Petition to the Congress of the United States* (New York, 1894, printed circular).

44. The files of the Baltimore and Ohio and the Chicago, Burlington, and Quincy contain numerous examples of WRA and ERA work in this regard. On these activities at the Burlington, see especially the letterbooks of Robert Harris, CBQ Papers, 3H4.1, 9W5.2; the letterbooks of C. E.

tary even went so far as to suggest he organize a bureau of inventions that would serve as a clearinghouse for information about railroad technology. The idea went nowhere, for it ran counter to the whole objective of internalizing the paths of innovation and minimizing the prominence of patents. Another enterprising secretary was fired after he allowed a patent holder (and, events later revealed, business partner) to advertise an invention as having the imprimatur of the WRA. Like the proposed bureau, this stunt managed to invert the essential function of the associations. Railroads were not in the business of certifying patents.

2.3 Engineered Innovation: Learning within Limits

It is tempting, perhaps, to interpret the story of the brake cases and the rise of the patent associations as merely an attempt by powerful business organizations to escape a rightful obligation. The backroom lobbying by railroad lawyers certainly lends some credence to the idea. The fact that railroads ultimately found redress in the courts, which so often provided them with safe haven in the hostile political climate of the late nineteenth century, perhaps furthers the suspicion. Others contemplating the cases may take an opposite approach and dismiss the dispute as little more than an anomaly created by those unscrupulous speculators, the "patent sharks."

Neither of these interpretations strikes me as persuasive. Without question, the brake patents were owned by business agents who were far removed from the actual inventors of the double-acting arrangements. But this hardly distinguishes them from thousands of other patents at the time. As Lamoreaux and Sokoloff (chap. 1 in this volume) amply demonstrate, agents routinely took possession of patents; their relentless efforts to collect compensation are testimony to the growing vibrancy of the market mechanisms that lay at the foundation of the patent system. The claims those agents made under the doctrine of savings, moreover, constituted something much more threatening to railroads than a mere nuisance that could readily be sidestepped by resort to political clout or judicial sympathy. The brake cases posed a threat so fundamental to the economic vitality of the railroads that some of their most respected executives personally led the drive to form the first national trade organizations in an effort to combat it. The concerns these men raised merited serious consideration from a panel of the country's most respected patent attorneys, from the entire U.S. Congress, and from the nation's highest courts. That the courts ultimately proved the source of relief had less to do with conspiracy than with the historic difficulties of legislating changes in a system that purports to govern a single, universal process of technical discovery. Quite simply, Congress could not accommodate the special concerns of railroads without sacrificing essential

Perkins, CBQ Papers, 3P4.4; and the in-letters of T. J. Potter, CBQ Papers, 3P6.21. At the Baltimore and Ohio, see Patents and Inventions File, B&O Papers.

features of a patent system that still functioned quite capably in most segments of the economy. Courts provided a forum of greater flexibility. As has so often been the case in the history of the patent system and in other areas of American law, judges found it possible to tailor a reform that would suit the particular circumstances, while legislatures foundered on the necessity of writing comprehensive provisions.

The fervency of the arguments and prestige of the participants provide more than ample evidence that the dispute mattered a great deal. Yet to fully appreciate why it mattered, we need to step back from the details and situate the conflict in the larger context of American railroading and the shifting patterns of innovation in the late nineteenth century.

The brake cases broke at a moment of transition for American railroading. The grand developmental epic had reached its denouement with the extraordinary postbellum boom of the northern and western economy. The ensuing financial collapse of the midseventies ushered in a dramatically different era. No longer able to reap the easy bonanza initially made possible by the marriage of railroad technology to virgin land and resources, railroads faced increasingly intense competition for traffic that might travel over any of several highly capitalized routes. Government, which had long been a source of subsidy for railroads, now threatened them with regulation that would further intensify the pressures to cut fares and shave costs. Though new frontiers would open during the 1880s in the Pacific Northwest and to a lesser extent in the Gulf Coast region, the paramount concern at many of the most influential carriers was now to utilize existing facilities fully and keep costs low. Managers at these established lines tried to attract a large and steady volume of traffic and push it through their network of tracks as smoothly as possible. In the words of Burlington president Charles Perkins, they focused on "running the machine."[45]

The passage from expansive development to operational stewardship dramatically altered the paths of technical change in the railroad industry. The new objectives imparted an emphasis on standardization and routine that often bordered on the obsessive. Managers sought to diminish the degree of personal autonomy that had long characterized railroad innovation and to impose order over their technical affairs through bureaucratic control. They withdrew from direct investments in their suppliers and turned responsibility for technology over to salaried engineers who appreciated the importance of uniformity and happily pursued incremental change that functioned within the existing system. Through laboratory experiment and controlled study of actual practice, these academically trained professionals substituted sustained analysis for the hit-and-miss approach of inventors and mechanics. Cooperation in technical affairs grew more formalized and extensive, as lines exchanged equipment and

45. The phrase comes from C. E. Perkins, "Memorandum on Organization," ca. 1890, CBQ Papers, 3P6.36. This paragraph and the remainder of this section are derived largely from Usselman, *Regulating Innovation*.

forged alliances that facilitated uninterrupted long-distance transport. Engineers from competing lines, together with representatives from major suppliers, negotiated technical specifications through trade associations and professional organizations that soon came to function as the centers of technical knowledge in the industry. Interestingly, the constitutions of these organizations expressly prohibited the advocacy of specific, patented articles in their specifications and standards.[46]

The rise of engineers to prominence in American railroading during the last quarter of the nineteenth century produced a situation rife with paradox. On the surface, railroading seemed to lack the technical vitality and spirit of experimentation that had characterized its first half century. Yet in reality the pace of innovation quickened. Though railroads now seldom provided Americans with the spectacular bursts of productive efficiency made possible by the initial substitution of rails and engines for roads and horses or canals and flatboats, the railroad industry itself attained far more impressive improvements in productivity than ever before.[47]

Railroads achieved this success, moreover, precisely *because* they constricted the realm of technical possibilities and pursued one grand objective with single-minded purpose. In order to simplify operations and reduce the possibility of accidents, for example, managers dictated that trains be run as slowly as possible, even if it meant purchasing additional cars. No one knew for sure whether this was the optimal mode of operation, but everyone appreciated that the choice brought an essential measure of order to what might have otherwise become a hopelessly complex balancing act. Railroads laid down another simplifying ground rule when they elected to maintain a reliable, trained workforce rather than press forward with labor-saving devices. Wary of disruptive strikes and of the growing strength of the brotherhoods, railroads kept workers in the system.[48] The technologies of steel rails and larger cars and locomotives enabled them to increase labor productivity without significantly altering work routines. The few new devices railroads willingly introduced, such as automatic signals, were intended to serve the ideal of ordered, regular movement of trains through the system.[49]

By laying down clear ground rules about operations and shunning innova-

46. Usselman, *Regulating Innovation.*

47. Albert Fishlow, "Productivity and Technological Change in the Railroad Sector, 1840–1910," in *Output, Employment, and Productivity in the United States after 1800,* ed. National Bureau of Economic Research (New York: Cambridge University Press, 1966), 583–646.

48. On workers and technological change in railroading, see Walter Licht, *Working for the Railroad: The Organization of Work in the Nineteenth Century* (Princeton: Princeton University Press, 1983); Shelton Stomquist, *A Generation of Boomers: The Pattern of Railroad Labor Conflict in Nineteenth Century America* (Champaign-Urbana: University of Illinois Press, 1987); James H. Drucker, *Men of the Steel Rails: Workers on the Atchison, Topeka, and Santa Fe Railroad, 1869–1900* (Lincoln: University of Nebraska Press, 1983); Steven W. Usselman, "Mixed Signals: The Annoying Allure of Automatic Train Control for American Railroads," paper presented at the annual meeting of the Society for the History of Technology, Washington, DC, 15 October 1993.

49. On railroad attitudes toward automatic signals, see Steven W. Usselman, "Changing Embedded Systems: The Economics and Politics of Innovation in American Railroad Signaling, 1876–1914," in *Changing Large Technical Systems,* ed. Jane Summerton (Boulder: Westview Press,

tions that threatened to disrupt them, railroads channeled the collective energies of mechanics, engineers, and suppliers into a few vital areas. They provided clear objectives around which a broad, impersonal technical community could organize. Virtually everyone connected with the railroad industry understood what was to be done and, more importantly, what should not be tried. They were immersed in what the historian Reese Jenkins has termed a "business-technological mindset."[50] Or, to draw on language that has recently informed much work in the economics of innovation, they functioned within a particular technical paradigm, in which the basic technology seemed to be following a natural trajectory.[51]

Engineers thrived in such a well-defined environment. With so much already decided upon and worked out, they could readily draw upon their abilities to optimize performance and apply those skills across a realm far vaster than any other of the day. In railroading, which had experienced a sustained and chaotic building boom for nearly half a century, engineers encountered a system with lots of "slack." Its outlines were clearly determined, but its details were largely unrefined. Engineers could readily identify ways to derive increased efficiency without disrupting the basic contours of the system. Indeed, they could accomplish a great deal simply by imposing a degree of order and routine on what already existed. Within the firm, managers organized procedures that channeled all improvements up to a central clearinghouse in the staff offices, where they were evaluated in departments headed by college-trained engineers and chemists. Often the explicit goal of superintendents of motive power and other staff officers was to limit experimentation taking place in shops and elsewhere along the lines.[52] Eventually railroads consolidated the design and test of locomotives, rails, and other essential equipment in these offices.[53]

1994), 93–116; Steven W. Usselman, "The Lure of Technology and the Appeal of Order: Railroad Safety Regulation in Nineteenth Century America," *Business and Economic History*, 2d series, 21 (1992): 290–99.

50. Reese V. Jenkins, *Images and Enterprise: Technology and the American Photographic Industry, 1839–1925* (Baltimore: Johns Hopkins University Press, 1975).

51. Giovanni Dosi, "Technological Paradigms and Technological Trajectories," *Research Policy* 11 (1982): 147–62. See also Edward W. Constant II, *The Origins of the Turbojet Revolution* (Baltimore: Johns Hopkins University Press, 1980).

52. When the Pennsylvania Railroad established the central office of superintendent of motive power, it stipulated that "he shall furnish others with standards and instructions required to insure a perfect uniformity in construction and repairs of all the company's rolling stock and machinery" (Minutes of the Meetings of the Board of Directors, 13 September 1882, 10:68, Board Papers, PRR Papers). His counterpart at the Burlington implemented a program of biannual meetings with master mechanics in order to extract information about experiments taking place along the line. The purpose was not to encourage experimentation, but to curtail it. The absence of such monitoring mechanisms, he warned, would "certainly bring about unlimited experimenting and [make it] exceedingly difficult . . . to maintain even a pretense of standards" (G. W. Rhodes to Besler, 22 November 1887, CBQ Papers, 3P4.51). Rhodes's boss, Burlington president Charles Perkins, had previously issued an edict expressly prohibiting employees from working on new technology on company time in the railroad's shops (memorandum from C. E. Perkins, 27 March 1880, CBQ Papers, 3P6.36). These documents indicate that the primary purpose of bureaucratizing railroad technical affairs was to encourage standardization rather than innovation.

53. The Pennsylvania Railroad founded chemical and mechanical laboratories in 1876. By the early twentieth century they had grown into some of the largest analytical testing facilities in the

Railroads also reached out to their major suppliers, such as the steel companies who rolled the rails and the builders who assembled the cars and locomotives. Both the capital-intensive process of manufacturing steel and the labor-intensive assembly work of the equipment builders held out enormous potential for learning by doing. Railroads facilitated the learning process by concentrating their purchases in a few major suppliers. These favored suppliers could capture economies of scale and rapidly accumulate knowledge, reaping benefits they supposedly passed on to the railroads in the form of lower prices and higher performance. To ensure they did, railroads insisted in their purchasing agreements on the right to examine procedures at the manufacturing sites and to set technical specifications that dictated details of production as well as design. The drafting of specifications, which was done through engineering organizations and by individual lines in negotiation with their suppliers, became an important medium for passing lessons learned in actual service and in the railroad's laboratories back to the manufacturers. Railroad test departments asserted a powerful influence over rail manufacture, dictating specifics such as the temperature at rolling and the amount of waste to be sheared from ingots at various stages of production, and their drawing rooms became the source of most locomotive design. In addition to providing such influence over the process of innovation, this close give-and-take with a limited number of suppliers also helped railroads maintain the uniformity they so valued.[54]

These new departures in the internalization of discovery did not, of course, obviate the need for policies regarding patents. Indeed, the growing emphasis on standardization and uniformity lent additional urgency to questions about licenses and liabilities raised by the brake cases. Outside suppliers who retained control of their patents might gain enormous leverage if their devices became standard equipment on cars that railroads now exchanged freely among themselves. Not surprisingly, railroads went to great lengths to avoid making commitments in their official standards to patented technologies that were available from only a single supplier. The patent associations played an essential role in that effort by alerting railroads to potential liabilities and by helping ensure that most innovations entered the pool of generic techniques. By enabling railroads to act in concert, moreover, the associations helped keep them from driving up the price of licenses.

None of the measures discussed here—the pooling of technical expertise and close linkages with technical experts at key suppliers, the channeling of innovation upward to standardizing bodies within the firm and across the in-

United States, and many other railroads had followed the Pennsylvania's lead. The experience of labs at the Pennsylvania can be traced through the files of the Association of Transportation Officers and those of the Motive Power Department, PRR Papers. Material on similar facilities can be found in the CBQ Papers and the Reading Papers. See also Usselman, *Regulating Innovation.*

54. Misa, *Nation of Steel.*

dustry, the growing reliance on engineers and the universal methods and language of scientific analysis—fits easily within a model of innovation that emphasizes the selection mechanisms of the market. In each case, railroads intervened in the marketplace and broke down the barrier between the creation of new technology and its use. Railroads also sought consciously to limit the number of participants in the market for innovation. They narrowed the potential sources of innovation by cultivating relationships with a few suppliers, and by cooperating with other lines to set uniform standards they restricted the number of selectors as well. Ultimately, railroads blurred the distinction between invention and selection so thoroughly that one could hardly detect the extraordinary innovation taking place.

Yet though the paths of innovation made possible by engineering studies and coordinated specifications often involved a conscious restructuring of market mechanisms, they by no means closed the process of technical change off from the forces of market competition. Engineers were creatures of capital who tied their work more closely to cost objectives than did most mechanics and inventors. They more readily situated their work within the larger context of the overarching system or paradigm and the competitive environment that encompassed them. Because engineers never ventured far from established, measured routines, they never lost sight of the potential economic returns of their activities. In their hands, innovation occurred as a routine by-product of the ongoing pursuit of operational efficiency, which in turn was driven by the competition to provide transportation services. The incentives to innovate thus were felt not through a market for novelty, but directly through the market for the ultimate, standardized product of low-cost transportation.

2.4 Parallel Pipelines, Persistent Patenters

In stressing the importance and accomplishments of engineered innovation to American railroading during the last quarter of the nineteenth century, I do not mean to imply that this approach to technical change entirely supplanted the patent system and the market for inventive novelty. As Lamoreaux and Sokoloff suggest (chap. 1 in this volume), the patent system provided an increasingly vibrant conduit of new technology in many segments of the economy during the very same period. Even in the railroad industry itself, a few conspicuous individual inventors such as George Westinghouse and George Pullman managed to retain control of patented technologies and build commercial empires around them. During the opening decades of the twentieth century, moreover, railroads would discover certain limitations of an approach to technical change grounded in engineering study and refinement. Faced with an extraordinary surge in traffic, they struggled with mixed success to relieve congestion by pursuing further incremental improvements. Their inability to respond more creatively may have resulted in part from uncertainty surrounding government regulation, but even in the absence of regulation, railroads clearly faced a tall order in attempting to reorient their technical efforts and encourage more radical departures from routine.[55]

Rather than hold up railroads of the late nineteenth century as exemplars of a "better" or "more efficient" approach to technical change, then, I would suggest instead that we conceive of technical innovation as flowing through two parallel and overlapping pipelines. The first operates through the patent system and the market for inventive novelty. This pipeline carries discrete, patented technologies suspended in air, water, or some other inert medium. It is fed by the creative acts of individuals. The second pipeline conveys a steady stream of incremental improvements, refinements, and analyses that blend into a somewhat homogeneous fluid. At its source this conduit taps a pool of expertise residing in salaried employees and other technical personnel, engineering societies, and colleges and universities. These pipelines are highly idealized, of course. In reality, innovation flows in neither the wholly atomized nor the seamlessly synthesized fashion I have suggested. Indeed, even my stylized formulation emphasizes that the pipelines of innovation overlap, creating a third channel in which particles of invention float within a fluid of steady refinement. Still, I think we can easily recognize these two distinct conduits in the ways we traditionally have characterized and investigated technical change. In this volume, for instance, we can readily identify the inventive pipeline in the study of Lamoreaux and Sokoloff (chap. 1), while it seems fair to say that the essay by Gavin Wright (chap. 8) explores matters largely encompassed by the engineering pipeline.

As those chapters suggest, the pipelines of innovation are by no means static entities. They are created and altered by a variety of institutional innovations and by the changing sources of supply that feed them. The patent system, for instance, operated more effectively over the late nineteenth century as intermediaries such as patent agents facilitated the flow of information about patents across a larger area. In assuming this role, agents not only distributed the fruits of inventive creativity more broadly; they also increased the pool of available new technologies by enabling creative individuals to concentrate their efforts on invention. Similarly, Gavin Wright describes how a variety of institutional developments, especially the rise of engineering education and the emergence of institutions devoted to the study of metallurgy and minerals, at once increased the supply of technical knowledge and facilitated its diffusion through the United States in the decades around the turn of the twentieth century.

American railroads, like firms in all industries seeking to innovate, attempted to tap these broadening streams of invention and knowledge by building a set of parallel pipelines dedicated to their own specific needs. Constructing these feeder lines to specific firms and industries necessarily involved

55. The changing course of technical change in early-twentieth-century railroading is discussed in the closing chapters of Usselman, *Regulating Innovation.* On government regulation, see Albro Martin, *Enterprise Denied: Origins of the Decline of American Railroads, 1897–1917* (New York: Columbia University Press, 1971).

a narrowing of the broader pipelines, as railroads tried to siphon off only the inventions and knowledge that appeared most promising to their particular needs. In the case of the patent pipeline, new instruments such as trade journals and patent agents helped railroads focus their inquiries and identify techniques of particular interest. (As Lamoreaux and Sokoloff demonstrate, the trends in patent assignments over time indicate that agents perhaps facilitated specialization as well as diffusion.) As the correspondence of Robert Harris and the history of the railroad patent associations suggest, such winnowing was motivated as much by a desire to extricate railroads from a mushrooming morass of patented alternatives as by a fervent desire to identify inventions they might otherwise have missed. The insider relationships railroads cultivated with chosen suppliers likewise served to simplify choices from a dizzying array of options. Later, some of those same relationships helped railroads construct a pipeline of engineered innovation. That pipeline took better shape with the development of engineering societies and trade associations, which linked railroads with one another and to the institutions described by Wright. Indeed, railroads were so prominent in early professional engineering circles that one can hardly separate the larger developments Wright chronicles from the ones discussed above in connection with railroads. Over time, however, a set of engineering organizations dedicated exclusively to railroading emerged.[56]

In constructing these dedicated, industry-specific pipelines and specifying more clearly the range of viable technical alternatives, railroads did not necessarily slow the pace of innovation. For as any student of fluid dynamics can attest, narrowing a pipe without reducing the volume of input will increase the rate of flow. This, I would argue, is precisely what happened in the late nineteenth century. By defining their technical objectives quite specifically, railroads accelerated the flow of knowledge into their industry from the rapidly expanding pipeline of expertise described by Wright. Metallurgists and materials scientists focused their efforts relentlessly on producing cars and locomotives of greater size and fuel efficiency, heavier and more durable rails, and superior lubricants. Together these innovations drove down costs in an industry dedicated to carrying a high volume of bulk commodities across long distances.[57]

With the pipeline analogy in mind, we can perhaps better comprehend the importance of the brake cases and the doctrine of savings. This dispute involved a fundamental issue in the construction of the engineering pipeline. In attempting to place an economic value on what railroads viewed as a generic improvement (i.e., a product of the engineering pipeline) and in threatening to

56. For excellent histories of two general engineering societies, see Daniel H. Calhoun, *The American Civil Engineer: Origins and Conflict* (Cambridge: MIT Press, 1960); Bruce Sinclair, *A Centennial History of the American Society of Mechanical Engineers, 1880–1980* (Toronto: University of Toronto Press, 1980). On engineering societies more specifically oriented toward railroading, see Usselman, "Running the Machine."

57. This analysis follows that of Fishlow, "Productivity."

return that amount to inventors, judges in the brake cases were in effect seeking to preserve the inventive pipeline as the primary source of innovation in railroading. If courts could identify hidden liabilities in the case of an innovation involving brakes, railroads wondered, what would keep them from acting similarly in vital areas such as rail design and car construction? Would courts always deem the inventive pipeline predominant? Later, the justices of the Supreme Court moved in precisely the opposite direction. Their notion that technical change proceeded across a broad front through the collective efforts of many anonymous practitioners effectively attributed the lion's share of innovation to the engineering pipeline. The Court's thinking did not compel railroads to pursue the engineering approach, but it did remove a potential blockage that may have prevented them from doing so.

The fact that these shifting judicial doctrines involved brakes is no mere coincidence, for braking was precisely the sort of technology that characteristically occupied the interstitial space where the two pipelines overlapped. Like most of the technologies that clearly fell into the inventive pipeline, braking technology usually involved mechanical parts. In contrast to many mechanical appliances that might be integrated into the design of a locomotive, moreover, brakes could easily be viewed and treated in isolation from the rest of the technological system in which they functioned. Applying double-acting brake rigging to a car did not involve any further alterations to that car or to the trains in which it traveled. In these respects, braking lent itself to a patent system that conceived of technology as discrete and particular, one that initially had required prospective patenters to submit working models with their applications. Techniques that fit most readily into the engineering pipeline, by contrast, often involved new processes or craft knowledge gained through experience or study.

While braking exhibited the physical attributes characteristic of much technology flowing through the inventive pipeline, it served purposes that placed it more in the realm of engineered innovation. In general, techniques that emerged from the engineering conduit served primarily to lower the costs of transportation rather than to provide qualitative changes in service. Such innovation was aimed at the concerns of railroad management and not at the experience of railroad customers, who usually encountered its effects indirectly in the form of lower rates rather than directly in the form of increased comfort or novel services. It was a rare passenger or shipper who could muster much excitement over the changing size and shape of the rails, no matter how strenuously railroads sought to persuade them that such changes were the ultimate source of falling rates and improved safety. A patented new folding bed in a Pullman car, by contrast, could evoke raves of enthusiasm from the traveling public while leaving railroad management unimpressed. Passengers did take some interest in the matter of brakes, of course, at least to the extent they perceived their safety and comfort were at stake. But an innovation such as the double-acting mechanisms constituted more of a refinement in existing techniques than a novel departure offering dramatically increased safety. Its greatest benefits were lower labor costs and reduced wheel wear, not shorter stopping distances, and railroads deployed it more extensively in freight service than on passenger cars.

One reason railroads shunned the double-acting mechanism in passenger service was the availability of an alternative, the continuous air brake. Patented in 1869 by George Westinghouse, the air brake rapidly became standard equipment on passenger trains and late in the century became a common feature of freight service as well.[58] Westinghouse used the air brake as a springboard into an astounding career as an inventor and manufacturer. His list of accomplishments included a second railroad-supply firm, the Union Switch and Signal Company, which at the turn of the twentieth century was far and away the largest provider of electric and pneumatic switching and signaling installations to American railroads.

On the surface Westinghouse's career seems to fly in the face of the notion that technical innovation in railroading flowed increasingly from a pipeline of generic incremental improvements. Upon closer inspection, however, we can see that in many respects Westinghouse is the exception who proves the rule. For his triumphs differed in two substantial respects from other innovations that occupied a middle position between inventive and engineered innovation.[59]

In the first place, both his braking and signaling technologies possessed technical attributes that distinguished them from many railroad innovations of the period. Each employed a novel technology—compressed air in the case of brakes, electricity in that of signals—that fell outside the established mechanical expertise of railroads. As a consequence, Westinghouse's railroad customers could not so easily absorb his designs into the reservoir of knowledge residing in their shops. With their arrays of interconnected compressors, valves, wires, motors, and other devices, moreover, Westinghouse's products appeared to function as complex, integrated systems that needed to be deployed wholesale or not at all. These qualities enabled Westinghouse to establish and maintain propr etary control much more readily than most other inventors. By patenting the essential hose coupling that connected brakes on each car with the air cylinder located on the locomotive, for instance, Westinghouse blocked railroads from mixing in brakes of alternative design. Deemed insurmountable by the WRA, the patent forced lines either to make a wholesale change to his devices or to maintain trains in multiple and incompatible formats, at severe cost to uniformity. Westinghouse thus leveraged the growing emphasis on standardization in precisely the way railroads hoped to prevent.

The second distinctive feature of Westinghouse's inventive enterprises was that he appealed past the railroads and pitched his products directly to consumers who rode the trains. This was especially true in the case of the air brake,

58. Steven W. Usselman, "Air Brakes for Freight Trains: Technological Innovation in the American Railroad Industry, 1869–1900," *Business History Review* 58 (spring 1984): 30–50.

59. Steven W. Usselman, "From Novelty to Utility: George Westinghouse and the Business of Innovation during the Age of Edison," *Business History Review* 66 (summer 1992): 251–304.

which he publicized masterfully by staging trials in the wake of a deadly accident at Revere, Massachusetts, that had attracted widespread attention from the public and from the state railroad commission. Though railroad executives were skeptical that automatic brakes would truly provide improved safety, they felt powerless to resist the overwhelming demand. "I have no doubt that [the air brake] will be made a subject of reference in advertisements," the Burlington's Harris wrote to a subordinate who resisted deploying the new device, "and that whether the traveling public would really be more safe or not, they would *think* so."[60]

In the case of freight operations, which occurred outside of public purview and involved extensive interchange of equipment among companies, railroads were willing to wait Westinghouse out. They employed air brakes only in especially demanding conditions such as fast freight and long mountainous descents, where increased control provided substantial economic benefits in the form of reduced wear and tear. Meanwhile, railroads laid plans to hold extensive trials of freight brakes upon expiration of Westinghouse's patents. To their chagrin, trials held at Burlington in 1886 and 1887 revealed severe limitations in all continuous brakes when they were deployed suddenly on long trains. Westinghouse seized the opportunity and introduced revised, "quick-action" equipment featuring valve work covered by new patents. Though these patents did not provide quite the ironclad protection he had enjoyed previously under the coupling patent, his threats of legal action kept all but the most steadfast competitors at bay. Railroads then resumed their holding pattern. Most did not place air brakes on freight equipment until after Congress passed legislation compelling them to do so. Government had done what railroads had expressly avoided—enshrined a proprietary technique in a standard—with Westinghouse again the beneficiary.[61]

60. R. Harris to C. E. Perkins, 25 April 1870, CBQ Papers, 3H4.1, 20:26–27, emphasis in original.

61. Westinghouse attempted to repeat his triumph in the area of railroad signaling—a technology that again appealed primarily to a sense of safety and that utilized the unfamiliar technology of electricity. In the 1880s he bought a fundamental patent covering the type of circuit required to make automatic signals operate in a fail-safe fashion. Most railroads, however, found they could do without his products, in large part because the public never mobilized a movement for automatic circuits. The few railroads that chose to deploy Westinghouse's signaling appliances did so on their own terms. They used them only in the most congested areas, where the automatic equipment could space traffic more effectively and keep it flowing more smoothly than any other means, thus saving vast capital expenditures on new track and reducing labor costs. Railroads tended to purchase signaling systems on a contract basis, with Westinghouse and his suppliers bidding to install customized plants at particular locations rather than sending lots of standardized components. Competitive advantages in the signaling business resulted in large measure from the knowledge acquired by engineers who designed custom configurations in the field and by skilled mechanics who translated those plans into unique devices. But patents also proved to be an important strategic tool in signaling. They enabled Westinghouse to build a stockpile of proprietary techniques that kept his competitors at bay, much as he and General Electric did in the field of electrical power. See Usselman, "From Novelty to Utility."

The annals of late-nineteenth-century invention contain a few other names associated with railroads, men such as Pullman with his palace cars and Swift and Armour with their fleets of refrigerated equipment. Like Westinghouse, these exceptional figures offered not operational efficiencies yielding lower rates and reduced fares (indeed, in the eyes of railroads these innovations threatened to complicate operations in ways that ran counter to the objectives of standardization and efficiency), but creature comforts such as greater safety and stylish service for which customers would pay a premium. Most technologies of this ilk appeared first in the passenger branch of the industry and diffused slowly if at all to the much larger and more lucrative freight side. (The refrigerated freight car—probably the most conspicuous possible exception—functioned as a component in a specialized branch of trade that catered to upper-class urbanites who wanted fresh dressed meat.)[62] The upscale consumers who traveled the rails and purchased the specialties railroads made available thus sustained markets for genuine novelty. Within those niches, the patent system still came into play.

But figures such as Westinghouse and Pullman remained conspicuous exceptions in the railroad industry of the late nineteenth century. Their devices, moreover, seldom contributed significant operating economies to the railroads themselves. Such benefits flowed instead from the pipeline of engineered innovation. By limiting their horizons and channeling their efforts, railroads discovered an enormous potential for improved performance. For them, less innovation was more.

2.5 Lessons

How typical were the nineteenth-century railroads? What does their experience suggest about the process of learning and discovery in other industries or at other times?

There is good reason to be cautious in drawing generalizations from the railroad experience. The conditions that gave rise to the patent associations resulted in large measure from characteristics peculiar to the railroad industry. Few other areas of enterprise offered the rich opportunities for technical exchange among seeming competitors. Few consumers of innovation possessed as much knowledge and expertise as railroads, and few had the sort of leverage over suppliers railroads obtained from their role as transportation providers. The fact that the brake cases were ultimately resolved through a flexible legal doctrine rather than through blanket legislative reform suggests that very different conditions prevailed elsewhere in the economy. As the career of George Westinghouse suggests, the patent system certainly remained central to the

62. On railroad resistance to refrigerator cars, see Mary Yeager, *Competition and Regulation: The Development of Oligopoly in the Meat Packing Industry* (Greenwich, CT: Greenwood, 1981).

course of innovation in emergent industries such as electric power and even retained a vital role within railroading itself in niches where novelty assumed special value.

The further internalization of discovery that followed the judgments in the brake cases likewise owed a great deal to the peculiar internal dynamics of the railroad industry. By the 1870s, American railroading had reached a point in its evolution that called above all for systemization and standardization. Owing to a combination of public policies and private incentives, the industry had grown heavily capitalized without having undergone intensive development and refinement. As many railroads stopped infiltrating new territory and turned their attention to moving commodities as efficiently as possible across long distances, the engineers took over. But engineers did not attain anything approaching such prominence in any other industry until the twentieth century. By then, moreover, railroads had begun to discover that the engineering approach to innovation had limits of its own. Under the stress of larger and more diverse traffic, the technical paradigm that had served railroads so effectively during the last quarter of the nineteenth century no longer yielded the anticipated benefits. Railroads found themselves groping for solutions that demanded more radical departures from routine and greater novelty than engineers could readily provide.

While considerations such as these suggest that the internalization of technical discovery described in this paper should not be taken as a normal state of affairs, we can nevertheless detect certain parallels between railroading and other industries. Some useful comparison, for instance, can be drawn between railroads and steel producers of the same period.[63] The distinguished Harvard economist F. W. Taussig noted these common trends in a 1901 essay for the *Quarterly Journal of Economics*. Entitled simply "The Iron Industry of the United States," the essay in reality sought to portray the recent growth of the entire American economy as largely a product of the pursuit of "routine and system." Taussig reserved especially high praise for "the wonderful growth of scientific and technical education" that had "[promoted] the rapid spread and complete utilization of the best processes." "They have been largely instrumental in enabling prompt advantage to be taken of chemical, metallurgical, and mechanical improvements in the iron and steel works," he went on. "Their influence has shown itself no less in the railways, the great buildings, the textile works, the manufacturing establishments at large."[64] Significantly, Taussig tied the spread of scientific expertise to the massive investment in machinery that had preceded it and to the organizational revolution that accompanied it. His contemporaneous analysis, like the more recent historical one of Alfred Chandler and that by Gavin Wright in this volume, thus suggests that condi-

63. Misa, *Nation of Steel.*

64. F. W. Taussig, "The Iron Industry of the United States," *Quarterly Journal of Economics* 14 (1900): 143–70, 475–508, quote from 488.

tions prevailing in the railroad industry reflected larger changes in the patterns of investment, the structure of markets, and the organization of technical knowledge. The shifting paths of technical change apparent in railroad patent policies thus may very well foreshadow emergent trends throughout the economy.[65]

Perhaps still more fruitful insights can be gleaned if we do not restrict our focus to the nineteenth century and concentrate instead on finding industries that passed through a series of transitions similar to those traced by the railroads. During the early twentieth century, for instance, the electrical industry entered a phase quite similar to that of railroading in the late nineteenth—a fact Thomas Edison perceived perhaps a bit prematurely when he opted out of the industry in the 1880s with the whining complaint that "working day and night to increase efficiency from 80 to 85 percent is an absurdity."[66] Electrical engineers in the early twentieth century, employing terms and concepts uncannily like those of their railroad counterparts a decade earlier, steered the industry toward procedures that would employ capital more intensively. Interestingly, the utility industry could pursue its relentless focus on lowering long-distance transmission costs and driving down the costs of production in large part because the two principal suppliers of electrical equipment—Westinghouse and General Electric—had pooled their patents.[67]

At about the same time, the automobile industry passed through a similar experience. For two decades, this infant industry had supported a vibrant competition among small firms offering products of novel design. Investors looking to impose some standardization and regularity on the chaotic new field hoped a key patent issued to Henry Selden might be used to block entry into the industry. When Henry Ford successfully challenged the Selden patent in court, however, auto manufacturers turned tail and agreed to pool all of their patents. The move skewed competition away from product differentiation sustained by patented technologies and toward economies of production achieved through relentless pursuit of incremental improvement by experts.[68] The great beneficiary, of course, was Ford himself. His synthesis of generic production technologies propelled him to the forefront of the industry.[69]

The experience of the postwar computer industry offers a third example. In its infancy, firms such as Sperry sought to establish dominant positions by

65. Alfred D. Chandler, Jr., *The Visible Hand: The Managerial Revolution in American Business* (Cambridge: Harvard University Press, 1977). The aggregate data of Ken Sokoloff and Naomi Lamoreaux (chap. 1 in this volume) lend some additional support to this idea.

66. Quoted in Harold C. Passer, *The Electrical Manufacturers, 1875–1900: A Study in Competition, Technical Change, and Economic Growth* (Cambridge: Harvard University Press, 1953), 104.

67. The basic sources here are Passer, *Electrical Manufacturers,* and Thomas P. Hughes, *Networks of Power: Electrification in Western Society, 1880–1930* (Baltimore: Johns Hopkins University Press, 1983). For further elaboration, see Usselman, "From Novelty to Utility."

68. See James Flink, *The Automobile Age* (Cambridge: MIT Press, 1988), 51–55.

69. David A. Hounshell, *From the American System to Mass Production, 1800–1932: The Development of Manufacturing Technology in the United States* (Baltimore: Johns Hopkins University Press, 1984).

designing and patenting basic approaches to computing.[70] Despite consistent efforts to the contrary, however, control of proprietary novelties seldom proved instrumental to success in this dynamic field. Technical change occurred so rapidly and across such a broad front that patents and licensing agreements often grew obsolete before their owners secured significant returns.[71] IBM's success in the industry ultimately owed more to its capabilities in maintenance, service, and production than to particular breakthrough inventions. The firm's most risky technical venture, its backward integration into semiconductor-component production, was more in the nature of a sustained exercise in learning by doing than a one-time inventive act.[72]

In drawing attention to these examples, I do not mean to suggest that technical innovation has always proceeded more rapidly or effectively in conditions where the patent system has been suspended and responsibility for innovation has passed to salaried experts and a tightly linked technical community. Rather, these cases may point to a stage theory of technical change. In every example a period of technical creativity sustained through mechanisms close to those idealized under the patent system gave way to a shaking-out period in which experts pursued sustained refinement through more internalized means. But the process did not stop there. As in the case of the railroads, which by the early twentieth century faced a crisis of congestion that called for more radical departures from existing practice, each of the episodes discussed above culminated in a resurgence of innovation flowing more clearly from the marketplace for novelty. During the 1920s, for instance, General Motors and other automobile makers turned the frontiers of competition back to product innovation with novelties such as the automatic starter and bright lacquer finishes. Similarly, profit centers in the electrical industries shifted toward consumer appliances during the 1920s. More recently, even the staid field of electrical generating equipment has been rocked by dramatic new technical departures, while in the contemporary computer business Microsoft thrives by marketing copyrighted programs. Still other examples of such passages might be found in telecommunications and in pharmaceuticals and other branches of chemicals, where innovation frequently appears to come in waves characterized by bursts of novelty followed by long periods of consolidation and refinement.[73]

70. Kenneth Flamm, *Creating the Computer: Government, Industry, and High Technology* (Washington, DC: Brookings Institution, 1988); Nancy Stern, *From ENIAC to UNIVAC: An Appraisal of the Eckert-Mauchly Computers* (Boston: Beacon Press, 1981).

71. Flamm, *Creating the Computer;* Richard C. Lewin, "The Semiconductor Industry," in *Government and Technical Progress: A Cross-Industry Analysis,* ed. Richard R. Nelson (New York: Cambridge University Press, 1982); David C. Mowery, "Innovation, Market Structure, and Government Policy in the American Semiconductor Industry: A Survey," *Research Policy* 12 (1983): 183–97.

72. This assessment is based largely on my essay "IBM and Its Imitators: Organizational Capabilities and the Emergence of the International Computer Industry," *Business and Economic History,* 2d series, 22 (winter 1993): 1–35.

73. Louis Galambos with Jane Eliot Sewell, *Networks of Innovation* (New York: Cambridge University Press, 1995); Louis Galambos and Jeffrey L. Sturchio, "The Pharmaceutical Industry

In his 1901 essay Taussig crowed that "American industry has shown not only the inventiveness and elasticity characteristic of the Yankee from early days, but that orderly and systematic utilization of applied science in which the Germans have hitherto been—perhaps still are—most successful."[74] Whether he accurately captured the direction of change or was correct in ascribing certain attributes to a particular culture may be open to question. But the distinction he drew remains useful. For it appears a recurrent feature of modern firms, industries, and economies that they must continually balance the fruits of "inventiveness and elasticity" with the benefits of the "orderly and systematic." It follows that the process of learning and discovery will trace no single course, and that innovation will continue to flow through multiple pipelines.

Comment Jeremy Atack

Steven Usselman's paper provides many insights into the relationship between patenting activity and the processes of innovation in large, technologically complex and capable organizations, but it also raises a number of fundamental questions. My purpose in this comment is threefold. First, I seek to set this work in the broader context of the interaction of patent law, economics and politics in the late nineteenth century—commentary that is also relevant to the paper by Lamoreaux and Sokoloff (chap. 1 in this volume). Second, I offer some additional evidence that is supportive of, and consistent with, the basic premises of both of these patents papers. Third, I discuss Usselman's interpretation of railroad behavior with respect to patents and patent case law.

While the market for inventions is usually modeled through the interaction of inventor-suppliers whose property rights are secured by the government through the patent system and a demand for improved devices and processes from users operating in a perfectly competitive environment, this is not the paradigm studied by Usselman. In his implicit model, inventions are interrelated rather than separable, the demanders are monopsonists in the input market for inventions and monopolists in the output market, demanders may also appear as suppliers and suppliers may produce no product of intrinsic merit and may not actually produce the product themselves. Not surprisingly, the resulting market works quite differently from the idealized market for inventions.

in the Twentieth Century: A Reappraisal of the Sources of Innovation," *History and Technology* 13 (1996): 83–100.

74. Taussig, "Iron Industry," 488.

Jeremy Atack is professor in and chair of the department of economics and business administration at Vanderbilt University and a research associate of the National Bureau of Economic Research. His research relies heavily upon the use of the manuscripts of nineteenth-century federal censuses of agriculture, manufactures, and population.

A Very Brief Primer on Patent Law

Congress was specifically granted the power "to promote . . . useful arts, by securing for limited times, to . . . inventors, the exclusive rights to their . . . discoveries" by the U.S. Constitution and was quick to act upon this authority, passing a number of different patent laws beginning with the law of 10 April 1790.[1] This law provided for up to fourteen years of protection for "any useful art, manufacture, engine, machine or device, or any improvement thereon not before known." Minor procedural revisions were made to the law in 1793 and 1800, but a more far-reaching change was made in 1819 when U.S. circuit courts were granted jurisdiction in equity of actions for patent infringements.

A major revision to the law was passed in 1836, creating a permanent experienced bureaucracy to review applications and grant patent protection. Subsequently, a number of other important changes were made to the law. In particular, as the law was originally written, a patent could not claim more than that to which it was entitled and, if void in *any* part, was void in whole. In 1837 these rules were eased where there was good faith by the patentee. In 1839 the law was amended to preserve the right to a patent within two years of discovery and allowing for the perfection of the invention possibly through public trials rather than requiring development in secret as the means of guaranteeing primacy.

Further minor modifications were made to the law as, for example, in 1861 when the patent duration was fixed at a single seventeen-year term, but the basics of the 1836 law survived into the twentieth century.

What is notable about this account of the evolution of patent law is the absence of major legislative action on patent law after the Civil War despite the fact that patent reform became the common goal of two powerful and otherwise successful lobbying groups—the National Grange and the railroads—which usually had opposing objectives. As Smith put it: "there has been, and doubtless still is in some parts of the country, a widespread hostility to the patent law. This feeling was, not many years since, very prevalent among the farmers of the West, and may still be so, though they are a class to whom the inventions of recent years have been of incalculable value. It may have been entertained and stimulated by the railroad companies, which have found it inconvenient to dispense with or pay for patented inventions."[2] Individually, the Grangers had been instrumental in securing the passage of laws regulating railroad rates while railroads had succeeded in winning federal land grants. However, their joint efforts to reform the patent system failed.

One possible explanation for this failure is that they were able to secure their

1. See U.S. Constitution, article I, section 8, paragraph 8. The description and chronology of patent law that follows is based upon Chauncey Smith, "A Century of Patent Law," *Quarterly Journal of Economics* 5 (1890): 44–69, especially 45–54.

2. Ibid., 58.

goals more easily through other channels. This was certainly not true for the Grange, for whom the profusion of patent infringement claims against farmers using driven (i.e., piped artesian) wells was of the greatest concern.[3] Railroads, however, may have been more successful in finding an alternative solution—the patent pool that lies at the heart of Usselman's story.

Patents and American Railroads

By the early 1850s, patents for devices to be used in railroading were being granted at a rate of about fifty per year. By the mid-1860s, the rate had increased tenfold—far faster than the railroad network had expanded.[4] Each of the dozens of railroads—some local, others regional or national—picked from the resulting menu of thousands of possible patented devices on the advice by their engineers informed by advertisements and demonstrations and governed only by personal prejudice. Those devices both large (such as steel rails, the telegraph, better signals, air brakes, and automatic couplers) and small (such as journal boxes, flues, and fireboxes) that made it through these filters were incorporated into railroad operations. Once embodied in the railroad's capital stock, innovations, taken collectively, had a major impact upon productivity which grew more than threefold or at an average annual rate of about 3 percent per year between the Civil War and 1900.[5]

However, despite the importance of innovation to railroad productivity growth, the managerial response to these inventions has not been well documented and much of what we do know is somewhat contradictory. For example, although J. Edgar Thomson, the president of the Pennsylvania Railroad, was an early and ardent champion of the steel rail and railroads consumed the majority of the nation's steel production before 1880, the railroads (including the Pennsylvania) seem to have been relatively slow to switch from iron rails to steel despite the technical and economic advantages of steel.[6] Similarly, what are probably the two most widely regarded railroad innovations (though

3. The case of the driven well has been extensively studied. See, for example, Earl W. Hayter, "The Western Farmers and the Drivewell Patent Controversy," *Agricultural History* 16 (January 1942): 16–28.

4. "Report of the Commissioner of Patents for 1852," U.S. Senate, 32d Cong., 2d sess., Executive Doc. 55, 438; "Report of the Commissioner of Patents for 1865," U.S. House of Representatives, 39th Cong., 1st sess., Executive Doc. 52, 18.

5. Albert Fishlow, "Productivity and Technological Change in the Railroad Sector, 1840–1910," in *Output, Employment, and Productivity in the United States after 1800* (New York: Columbia University Press, 1966), 583–646, especially 626.

6. For statistics on the growth of the steel industry see Peter Temin, *Iron and Steel in Nineteenth-Century America* (Cambridge: MIT Press, 1964). For a discussion of the laggard rate of adoption of steel rails, see Jeremy Atack and Jan Brueckner, "Steel Rails and American Railroads, 1867–1880," *Explorations in Economic History* 19, no. 4 (1982): 339–59; C. Knick Harley, "Steel Rails and American Railroads, 1867–1880: Cost Minimizing Choice: A Comment on the Analysis of Atack and Brueckner," *Explorations in Economic History* 20, no. 3 (1983): 248–57; Jeremy Atack and Jan Brueckner, "Steel Rails and American Railroads, 1867–1880: Reply to Harley," *Explorations in Economic History* 20, no. 3 (1983): 258–62.

ultimately of far less economic significance than the steel rail)[7]—air brakes and automatic couplers—were not fully adopted until Congress in 1893 mandated their use in all interstate commerce effective August 1900.[8]

Early on, some of this reluctance might be explained by the efforts of individual railroads to preserve their own distinctiveness as part of their grand designs to monopolize traffic along a particular route. Many of these idiosyncrasies probably originated in and manifested themselves through isolated adoptions of particular patented devices and processes that all too often became indispensable to the smooth functioning of day-to-day operations of the individual railroad.

Most of these specific innovations are undocumented, but we do know a great deal about one obvious example—the adoption and persistence of different track gauges. These not only effectively prevented shippers from taking advantage of the arbitrage opportunities afforded by small freight-rate differences between destinations but also essentially isolated communities one from another if they were located on tracks of different gauge. In 1861, for example, while most of the eastern seaboard railroads had adopted the English 4′ 8½″ gauge, the Cleveland and Pittsburgh used 4′ 10″ (still useable by "standard" locomotives and rolling stock though perhaps with some increase in risk of derailment and additional wear and tear), while the Grand Trunk used 5′ 6″ and the New York and Erie had a 6′ gauge.[9] So long as this situation persisted, extensive trade between, say, Binghamton (on the New York and Erie) and most of Pennsylvania (where the standard gauge predominated) was unlikely, and communities could be held hostage.

As the advantages of cooperation became clearer to the railroads, barriers to exchange and interchange came down, but before the full benefits of an integrated rail system could be realized, there had to be a greater degree of uniformity across the different rail networks. This would potentially encompass almost all aspects of system operation from track design to rolling stock to shipment billing and tracking. The marketplace for ideas, while rich, was also full of confusion, particularly for a new technology. Vested interests and competing claims—some true, some false, some exaggerated, some modest, some from insiders, others from outsiders—vied for attention. How was one to choose which standard to adopt?

7. Fishlow, "Productivity and Technological Change," 639, asserts that steel rails were at least three times as important as the air brake and the automatic coupler.

8. Interestingly, railroads made two contradictory arguments. On the one hand they claimed that the devices were unproven and ineffective. On the other they asserted that adoption was proceeding as quickly as possible. See Interstate Commerce Commission, *Annual Report on the Statistics of Railways in the United States for 1891* (Washington, DC: Government Printing Office, 1892), 45; U.S. Senate Interstate Commerce Committee, *Hearings in Relation to Safety Couplers and Power Brakes in Freight Cars,* 51st Cong., 1st sess, 30 April and 14–16 May 1890. See Fishlow, "Productivity and Technological Change" 634–35.

9. George R. Taylor and Irene Neu, *The American Railroad Network, 1861–1890* (Cambridge: Harvard University Press, 1956).

The Railroad Machine and Repair Shop

The nature of railroading further complicated the situation. As extremely complex, integrated technical systems, the railroads found it difficult, if not impossible, to determine the precise contribution of each device or process to their cost savings, revenues, or profits. Outside inventors would thus have been at an even greater disadvantage in pricing the products of their ingenuity. But, even if a dollar figure could be attached to specific savings or additional earnings from individual patented devices, the railroads questioned whether their inventors were entitled to the full amount of the benefits, since parts of these at least arose from the railroad's market power and success. The number of outside inventor-suppliers was large; the number of railroad demanders relatively small and getting smaller as railroads consolidated and cooperated.

In the absence of a well-developed pool of outsider suppliers throughout much of the nineteenth century, the railroads built much of their own equipment and facilities and maintained large repair facilities to keep this capital in good working order. This was especially important given the high ratio of fixed to total costs for railroads. Although relatively little is known about these railroad machine shops and repair facilities, many of them were large whether measured in terms of employment or in terms of value of their output. Indeed, many would have ranked among the largest industrial enterprises of the time had they been separate firms. Some idea of their importance can be gauged from the data presented in table 2C.1, which lists some statistics about a few of the larger repair facilities taken from the manuscripts of the censuses of manufactures.

Based upon these data it seems obvious that railroad repair shops were major employers. Most employed hundreds of workers in a single facility. Some employed thousands. Many of these individuals must have been relatively skilled mechanics and machinists. With 643 employees in 1850, the Philadelphia and Reading Railroad machine shop, for example, accounted for 13 percent of machinists and millwrights in Pennsylvania and more than 2 percent of the national total reported by the 1850 census. It also seems reasonable, based upon the statistics in table 2C.1, to infer that these repair facilities proliferated and grew over time.

By virtue of their size and the complexity of the systems that they built, repaired, and maintained, these machine and repair shops must have served as informal schools for engineering practice, as repositories of engineering expertise, as storehouses of knowledge about what worked, what didn't, and why, and as test facilities for prospective innovations. These facilities were thus uniquely positioned to advise railroad management on which inventions worked and which didn't.

Given the complexity of the systems that they were called upon to build and repair and the interdependence between these systems, the railroad machine and repair shops found it expedient to license the right to manufacture patented

Table 2C.1 Partial Listing of Large Railroad Repair Facilities, 1850–80

Year	Railroad	Capital Invested ($)	Employees	Value of Output ($)	Repairs as % of Output
1850	Philadelphia & Reading	800,000	643	250,000	100
	Vermont Central	30,000	95	136,000	100
1860	Alabama & Tennessee	na	50	75,000	na
	Central Ohio	100,000	155	150,000	na
	Louisville & Nashville	165,000	250	225,000	na
	Marietta & Cincinnati	28,000	100	60,000	na
	Michigan Central	400,000	90	150,000	na
	Mississippi	6,000,000[a]	54	54,438	79
	North Carolina	400,000	60	52,950	76
	South Side	20,000	30	133,000	100
	Southern	na	60	100,000	na
	Vermont Central	750,000	144	268,300	na
	Western & Atlantic	7,500	70	207,500	na
1870	A.G.	100,000	95	72,850	77
	Burlington	75,000	278	730,989	56
	Central of New Jersey	700,000	300	97,000	43
	Cleveland & Pittsburgh	150,000	160	337,070	39
	Connecticut & Passumpsic	350,000	106	175,592	47
	Erie	400,000	547	1,301,277	39
	S.S.M.S.	399,038	193	459,158	na
	Vicksburg & Meridian	210,000	150	339,800	83
	Vermont Central & Canada	115,000	374	513,260	48
1880	Chicago & Northwestern	1,642,662	1,120	2,799,474	na
	Chicago, Burlington & Quincy	250,000	750	625,000	na
	Chicago, Burlington & Quincy	na	455	652,275	na
	Chicago, Rock Island & Pacific	750,000	799	990,665	na
	Chicago, Rock Island & Pacific	350,000	822	600,000	na
	Decatur Division of Louisville & Nashville	30,000	59	66,870	na
	Illinois Central	1,000,000	922	912,686	na
	Missouri Pacific	100,000	350	650,000	na
	Nashville, Chattanooga & St. Louis	130,000	200	185,887	na
	P.C. & S.L.	100,000	351	346,571	na
	Pennsylvania	1,525,463	1,334	2,427,043	na
	Pennsylvania	1,914,669	2,069	2,531,277	na
	Pennsylvania	na	764	1,305,000	na
	Philadelphia & Reading	120,000	130	303,000	na
	Philadelphia & Reading	360,000	551	501,000	na
	Philadelphia & Reading	350,000	400	475,000	na
	Union Pacific	35,000	11	140,000	na
	Wabash, St. Louis & Pacific	na	250	309,107	na

Source: Unpublished data from the manuscript censuses of manufactures collected by Fred Bateman and Thomas Weiss (1850, 1860, and 1870) and by Jeremy Atack and Fred Bateman (1880). These facilities are those that, fortuitously (as a result of their relative size measured by gross ouput), happened to be included in the Bateman-Weiss and Atack-Bateman large-firm samples.

Note: na = not available.

[a]Almost certainly the capital invested in the railroad, not just the machine shops.

products rather than purchase them from outside suppliers. Indeed, over time, these data from the largest machine shops show that, where repairs were separately identified, the share of repairs as opposed to production of new locomotives, rolling stock, and other railroad equipment declined over time. This finding is consistent with Usselman's story of growing railroad involvement in producing their own equipment rather than buying from outside sources.

By producing patented devices "in house" under license, railroad repair shops eliminated the possibility of being held hostage to external supply uncertainties with respect to price, quality, and delivery. At the same time they gained engineering expertise that should have proved useful not only in the production and repair of the product in question but that might also have led to the design and creation of new and improved models, possibly of a sufficiently radically new design to not be covered by the original patent. That engineering expertise and experimentation, if properly documented, could also serve as a basis for successful challenges (known as "interferences") to the grant of a patent or its enforcement on the grounds that the device lacked originality.

At what point these modified devices became entirely new products and what the economic contribution of the original idea was became matters of heated debate both inside and outside the courtroom. From the standpoint of the railroads, they had committed substantial resources to guarantee the success of a particular device, and they saw little or no reason to share those benefits or the profits of their monopoly power with outsiders.

Here lay a bone of contention between outside inventors and insider innovators. The successful outside inventors, such as George Westinghouse, resisted railroad pressure to license their technology for insider manufacture. The less successful, such as Henry Tanner, assignee of the Thompson and Bachelder patent on double-acting brakes, eventually lost control of their invention. This latter case is one to which Usselman refers in his paper. It eventually reached the Supreme Court before being resolved in favor of the railroads.

Railroad Patents, the Courts, and Patent Pools

Elsewhere, Usselman has dealt at length with the issues in the case of the *Chicago and Northwestern Railway Company V. Thomas Sayles* (97 U.S. 554)—otherwise known as the Tanner brake case—but it is worthwhile repeating some of the details here to illustrate the problems confronting the railroads given the nature of American patent law at the time.[10] The Chicago and Northwestern Railway Company was only one of many railroads sued by Sayles for patent infringement.[11] Moreover, Sayles was an active litigant in at

10. Steven W. Usselman, "Organizing a Market for Technological Innovation: Patent Pools and Patent Politics of American Railroads, 1860–1900," *Business and Economic History,* 2d series, 19 (1990): 203–22.

11. Sayles also appears as plaintiff in patent litigation against the Chicago, Burlington, and Quincy Railroad (case 12,416), the Dubuque and Sioux City Railroad Company (case 12,417), the Erie Railway Company (case 12,418), the Grand Trunk Railway Company (case 12,419), the

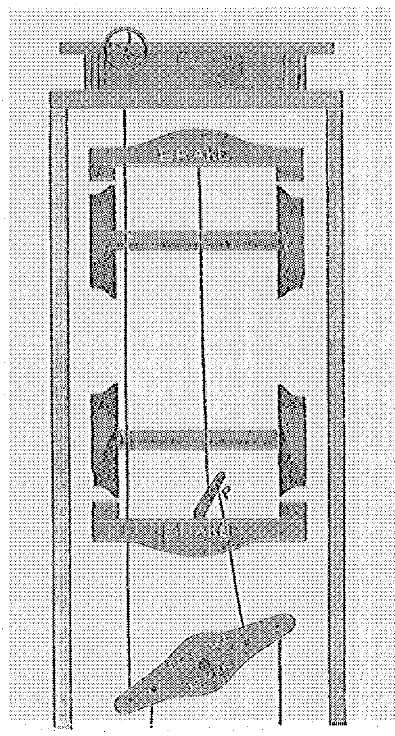

Fig. 2C.1 The Tanner double-acting brake
Source: Chicago and Northwestern Railway Company v. Thomas Sayles, 97 U.S. 554, 1053.

least one other patent case that was totally unrelated to railroads and braking systems.[12]

At issue in *Chicago and Northwestern Railway Company V. Thomas Sayles* was a patent covering so-called double-acting brakes. These operated simultaneously on a pair of wheels in the trucks at each end of a railroad car and, by an ingenious arrangement of pivots, arms, and operating rods, were equally efficient in braking regardless of the direction of travel (see figs. 2C.1 and 2C.2).

A number of patents were issued by the Patent Office covering these devices, the first in November 1848 to Charles Turner, another in October 1849 to Nehemiah Hodge, a third to Francis Stevens in November 1851, while the patent under which suit was filed was not granted until July 1852. Although the latter patent was the last of the series to be granted, it claimed primacy as a correction

Oregon Central Railway Company (case 12,423), the Richmond, Fredericksburg, and Potomac Railroad Company (case 12,424), and the South Carolina Railroad Company (case 12,425). See 21 *Fed. Cas.* 597–617.

12. See *Sayles v. Hapgood et al.*, case 12,420, 21 *Fed. Cas.* 605.

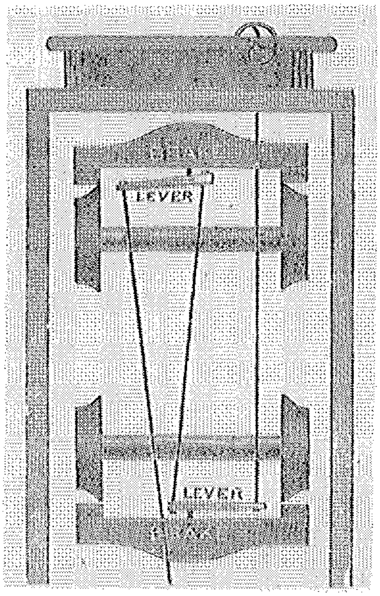

Fig. 2C.2 The Stevens double-acting brake
Source: Chicago and Northwestern Railway Company v. Thomas Sayles, 97 U.S. 554, 1054.

of an earlier, rejected patent originally filed in June 1847 by Lafayette Thompson and Asahel Bachelder. Some issues at stake in the case were additions and modifications to the patent between the date of initial filing and acceptance.

The case on appeal was one of several filed beginning in the early 1860s against individual railroads claiming for patent infringement. Specifically, Henry Tanner, assignee of the Thompson-Bachelder patent, alleged that Chicago and Northwestern Railway had infringed upon his patent rights from 1 June 1859 by their use of this device without payment, while the railroad defended itself on grounds of prior invention and preexisting use and by denying that their double-acting braking system infringed on the Tanner patent.

The circuit court had found for the plaintiff and after various legal wrangles and maneuverings had awarded damages in the amount of $63,638.40 "being $41,280 for savings in wages of brakemen, and $22,358.40 for savings in car wheels" (97 U.S. 554, 1054).

The illustrations incorporated into the Supreme Court decision (figs. 2C.1 and 2C.2) demonstrate part of the problem facing railroads: it is hard to distinguish fundamentally different principles between these two patented braking devices, thus making it impossible to determine to whom payment should be made unless the brakes that one was using corresponded exactly with one of these descriptions.

In rendering the Supreme Court's decision, Justice Bradley touched on the question of novelty, declaring "[l]ike almost all other inventions . . . [it] came when, in the progress of mechanical improvement, it was needed; and being sought by many minds, it is not wonderful that it was developed in different and independent forms, all original, and yet all bearing a somewhat general resemblance to each other. In such cases, if one inventor precedes all the rest, and strikes out something which includes and underlies all that they produce, he acquires a monopoly, and subjects them to tribute. But if the advance toward the thing desired is gradual, and proceeds step by step, so that no one can claim the complete whole, then each is entitled only to the specific form of device which he produces." On the question of primacy, Justice Bradley noted that "in 1847, when Thompson and Bachelder filed their application . . . and in 1846, when it is said that they completed their invention, double brakes were already in existence, formed as theirs was . . . in 1842 or 1843." If so, these fell well outside the two-year window of opportunity attending first public use prior to patent application, even though none of these earlier examples was available for examination. Lastly, the justices addressed the issue of overlap between the Stevens brake (fig. 2C.2) and the Tanner brake (fig. 2C.1), finding that the central feature of the Tanner brake—the central lever—had no analog in the Stevens brake, ruling therefore that it was "essentially different" and that "the two are to be regarded as independent inventions, each being limited and confined to the particular contrivance which constitutes its peculiarity." As a result the circuit court decision was vacated, but only after some sixteen-plus years of litigation. Little wonder, railroads wanted to find a different answer to their patent problem.

That solution, according to Usselman, lay in the establishment of patent pools that would eliminate the "divide and conquer" strategy for the outside inventor while strengthening the railroads' hand by pooling information about prior experiments that might usurp outsider claims to primacy and novelty in their inventions. The New England railroads were the first to organize, agreeing upon a common defense against a patent infringement suit in 1866. The following year, many of the nation's railroads joined either the Eastern Railroad Association or the Western Railroad Association, agreeing to pool information regarding their own experimentation and a common defense against patent infringement suits. These patent pools predate the collusive pools that the railroads eventually established to allocate market shares or eliminate price competition and price volatility.[13] Missing from Usselman's discussion is any evidence regarding their success, particularly the extent to which the pooled notes of insider experiments were used successfully to challenge the primacy and novelty of an outside invention.

The impetus behind the organization of patent pools came, according to

13. There was at least one earlier trade organization, the National Railway Convention, but this does not seem to have had patents or the adoption of standards as its principal concern. See Colleen A. Dunlavy, "Organizing Railroad Interests: The Creation of National Railroad Associations in the United States and Prussia," *Business and Economic History*, series 2, 19 (1990): 133–42.

Usselman, from the adoption by the courts of a new measure of the losses to inventors from patent infringement known as the doctrine of savings, which favored inventors over innovators. The problem with this interpretation, however, is one of timing (whether with the Tanner brake case or others, which assessed damages for patent infringement). The timing is tight to rest the *entire* argument on a new, untested legal ruling. The initial decision in the Tanner case in favor of the plaintiff was rendered in February 1865. The first railroad patent pool was established the following year. The Tanner case was subsequently reopened on the basis of new evidence (uncovered, perhaps, as a result of information pooling, although the Supreme Court record does not say when or precisely why) and the original decision was reaffirmed in 1871, only to be set aside by the Supreme Court in 1878. The basis of the damage calculation in the Tanner case was, however, substantially modified in December 1871 to the disadvantage of patentees in *Mowry v. Whitney* (14 Wallace 620), in which the plaintiffs had originally been awarded the *entire* profits from the manufacture and sale of annealed railroad wheels. On appeal the Supreme Court ruled that the plaintiff was "not entitled to receive more than the profits actually made in consequence of the use of [his] process" and directed that "what advantage did the defendant derive from using the complainant's invention over what he had in using other processes then open to the public . . . are his profits. They are all the benefits he derived."[14] The railroad patent pools, however, endured much longer than the legal rulings that allegedly stimulated their creation.

If adverse court decisions were not the sole or even the dominant source of the drive to organize patent pools, what was? My answer is a simple one: the creation of railroad patent pools slowed the pace of technical change from both within and without. For outside inventors, the pooling of information among the railroads reduced the expected return from invention by lowering the likelihood of novelty and by diminishing the probability of adoption by any subset of railroads. On the inside, collusion stilled the winds of "creative destruction" that jeopardized the value of existing investment. This is what abstract theory suggests.[15] It is what the casual evidence suggests. But it is not what Usselman concludes and that, I think, is cause for a second look.

14. Ibid., 649, 651.

15. Partha Dasgupta and Joseph Stiglitz, "Uncertainty, Market Structure, and the Speed of R&D," *Bell Journal of Economics* 11 (1980): 1–28.