TELEGRAPHS TO INCANDESCENT LAMPS: A SEQUENTIAL PROCESS OF INNOVATION

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ABSTRACT

This paper outlines a sequential process of technological innovation in the emergence of the electrical industry in the United States from 1830 to 1880. Successive inventions that realize the commercial possibilities of electricity provided the foundation for an industry where technical knowledge, invention and diffusion were ultimately consolidated within the managerial structure of new firms. The genesis of the industry is traced, sequentially, through the development of the telegraph, arc light and incandescent lamp. Exploring the origins of the telegraph and incandescent lamp reveals a process where a series of inventions and firms result from successful efforts to use scientific principles to create new commodities and markets.

Introduction

A perspective of technical change as the embodiment of scientific principles in an invention is one that has been explored widely.[1] A larger problem looms, however, beyond a simple accounting of the commercial realization of a new product or production process. Put precisely, the question is whether technological change can be characterized as a sequential process of development which yields a stream of complementary inventions. In the present instance, this question is considered by extending what we might term the scientific principles of electricity to commercial innovation path, found in the origins of the telegraph, into a sequence of innovation in electrical systems which culminates, not in a concluding sense but by the time limitation placed on the study, with the development of the incandescent lamp. The period considered covers roughly fifty years in electrical generation and transmission innovations from 1830 to the early 1880s, and is restricted to the United States.

A sequential characterization of technological change is potentially informative for several reasons. First, the analysis of innovation moves from investigating the development of a single invention to considering a process which generates a series of related inventions. Such a process, over an extended period of time, points toward and ultimately suggests that scientific discovery and the subsequent inventions that result from it generates both technical change and new technical knowledge.

The second compelling reason to analyze a sequence of related inventions is associated with the social organization of the innovation process. In this respect the personal and professional connections that are identifiable between and among inventors, the emergence of firms, and the managerial and financial hierarchies that evolve to realize the commercial possibilities of invention, are important aspects of innovation. The technological and organizational aspects of innovation are concomitant processes which generate and diffuse new products and production processes in an increasingly coordinated fashion. In the case of the telegraph and incandescent light, the process of innovation incorporates the contributions of many individuals, and technical change is institutionalized within the firm by the close of the period under consideration.[2]

Finally, the process of technical change and its attendant management and organization within firms increasingly creates and structures markets, in more deliberate ways, relative to the demand for new inventions. This is noteworthy in the creation of revolutionary consumer and producer commodities in the form of the telegraph and incandescent lamp. Although questions pertaining to the introduction and diffusion of new products can be addressed from a better understanding of the structure of markets and demand relative to technical change, the primary objective of this study is to locate the telegraph and incandescent light within a realm which proves conducive to nurturing the development of related inventions.

The Origins of the Telegraph

Accounts that conceptually note the potential for communicating over distance by using a charge of electricity along a line date from soon after Benjamin Franklin's kite experiments, which were conducted between 1748 and 1752. The term "telegraph" first appears in the 1794 edition of the Oxford English Dictionary to describe a semaphone signaling system that was devised by Claude Chappe, a French physician, in 1792.[3] It was apparent, even in the earliest conceptual schemes, that three essential components were required for a feasible telegraph; a mechanism to send a message, a means of moving the message between two points, and a receiving mechanism. A focusing of efforts to develop a mechanical telegraph which satisfied these requirements proceeded from the knowledge of electrical principles and eventually converged on the possibility of using a charged wire to signal between separate sending and receiving points for communication.

In tracing the emergence of a mechanical telegraph, it is possible to identify the evolution of the separate motor and transmitting mechanisms and the tool or working machine components as they progressed from conception to mechanism. The motor and transmitting mechanism became explicitly similar technical problems since they were both incorporated in the propagation of an electrical charge along the wire. The tool, or working machine, components of the telegraph would eventually incorporate both the sending and the receiving mechanisms after its commercial introduction in the United States.

Two advances in scientific principles prior to 1820 were decisive in solving the motor and transmitting mechanism problem of electrically propagating a telegraphed signal. The first was the pile battery experiments of Alessandro Volta in Italy at the turn of the century, which produced a sustained discharge of electricity for the first time.

Volta piles, which were stacks of zinc and silver disks separated by leather soaked in brine, superseded the Leyden Jar, which had previously unleashed only a brief impulse of electricity. The Volta pile thoroughly revised conceptions of the nature of electricity, which had associated it with fire, to where electricity was seen as an invisible substance that possessed magical properties. The mysterious qualities of electricity led Luigi Galvani (1737-1798) to consider its life giving potential when his dead frogs suddenly twitched from electrical discharges. Volta, on the other hand, was "shocked" and disappointed when, after passing an electrical charge through his head, noted only blurred vision and ringing in the ears.[4]

Volta piles were used in an early electrolytic telegraph developed by Samuel von Soemmering in 1809, in Germany. This primitive device had alphabetically identifiable wires which sent an electric charge from a Volta pile to indicate a signal through the discharge of hydrogen bubbles in a solution that each wire was immersed in. The system was cumbersome, but attempts were nevertheless made to use it commercially.[5]

The second important scientific advance for the telegraph was Hans Christian Oerstead's discovery of the reverse polarity between electricity and magnetism in 1819, in Denmark. Known later as the principle of electromagnetism, Oerstead's work would be decisive for the commercial realization of the telegraph since electromagnetism made it possible to note the presence of the electrical signal by the deflection of a magnetic needle on the receiving end of the wire. This meant armature devices could be created for the receiving mechanism which would use electromagnets to indicate the signal. Experiments with such armatures resulted in the simultaneous discovery of electromagnetic induction by Michael Faraday, in England, and Joseph Henry, in the United States, in 1831.

Perfecting the Telegraph Apparatus

The only technical application of the scientific knowledge of electromagnetic induction in 1831 had been in telegraph experimentation. But three problems continued to hamper the realization of a commercially feasible telegraph. First, the signal died out when the length of the wire was increased beyond a few hundred feet. Larger and more efficient Volta piles had failed to appreciably improve transmission over longer lengths of wire. A separate relay device was needed, and its absence was the second technical problem that limited the development of the telegraph. These shortcomings directed efforts to obtain a single solution which would solve both the signal strength and the relay problems. The principle of the two stage relay, where a small increment of energy released a larger quantity of latent energy, was understood through the hammer action of a firearm. Inventive attention sought to create an electrical relay device, based on the same principle, that would restore the strength of the current between separate sections of wire. This, however, created a third technical problem since a reduction or an increase of current at each relay point and at both ends of the wire was needed to control and ensure safe operation. A device that would transform the electrical current into manageable voltages was required.

The development of the motor and transmitting mechanisms in the telegraph in the United States after 1831 was associated with a process of technological convergence that provided a single solution to all three technical limits. The three problems could essentially be broken down into the source, transmission and regulation of current. A clear sequential process of innovation which rendered separate, but related, inventions is explicit in the ordering of these problems. The solution emerged in the technical application of electromagnets to the motor and transmitting mechanism in the working tool of Samuel Morse's telegraph.

On the receiving end of the Morse telegraph an electromagnet served as a transformer and simultaneously moved an armature device to indicate the signal. At separate relay points along the length of the wire the current activated an electromagnet, which opened and closed a battery circuit and transferred the signal to an outgoing circuit that proceeded to the next relay point. In this manner the process was repeated indefinitely, over intervals of about twenty miles. This scheme, which had the battery as the electrical source and electromagnets for relays and transformers, was scientifically understood by 1838 in the United States and would remain basically unchanged until the early 1870s, when dynamos replaced batteries as the source of the current.

Technical developments in the telegraph are one aspect of the supply-side of the process of innovation. Equally important is a social dimension to invention which also determines the eventual introduction of a new, viable commodity.

The 1830s was the key decade for scientific investigations which led to the commercial realization of the telegraph in the United States in the 1840s. Joseph Henry, in experiments at the Albany Institute in Albany, New York, had demonstrated how electrical current produced by primitive iron armature devices could be altered by increasing or decreasing the turns of wire on the armature.[6] Henry's first devices resembled the rocking beam of early steam engines, but the work pointed toward a practical relay and primitive transformer. His attempts to combine the sending and receiving mechanisms into one working tool are reflected in the complicated schema of the Samuel Morse caveat, filed with the United States Patent Office in October, 1837. This large, unwieldy machine bore little resemblance to the sending and receiving apparatus of just eight years later. Indeed, the only component that remained intact from Morse's first patents, which were granted in 1840, was his code, which had been conceptually worked out in 1835.[7]

The significant technical refinements in the first feasible telegraph came not from Morse, but from a group of associates who helped him install the thirty-seven mile line from Baltimore to Washington in 1844. Morse was the opportunistic promoter of the telegraph, not a scientific genius who could lay claim to the invention itself.[8] Instead, the commercial realization of the telegraph was the outcome of a technical and social process of innovation which brought together the efforts of some of the leading scientific and managerial minds of the time. Ezra Cornell, the founder of Cornell University, was responsible for the installation of the wire. His initial attempt to bury the cable failed because of poor insulating materials, and used up all but $7,000 of the

$30,000 federal appropriation that Morse had secured from the federal government.[9] Alfred Vail, a prominent iron manufacturer, produced the wire, which was then strung on poles installed along a railroad line.[10] The overhead line and the use of insulators had been suggested by Henry, who provided technical advice on a relay for the Morse system in 1839. But to complete the project Cornell had to round up thousands of glass doorknobs to use as insulators, since insulators had no prior use.[11]

Vail, who signed a cooperative agreement with Morse in 1838, was the most important figure for the considerable technical refinements in instrumentation between 1837 and 1844.[12] In addition to inventing a receiving device which printed Roman numerals, it was Vail who developed the key transmitter, which replaced Morse's bulky port rule apparatus. The receiving and transmitting devices were still separate, however, and the receiving mechanism was operated by an electromagnet armature which pencil-printed the dots and dashes of the code on a roll of paper. The familiar sounder, or clicker, which proved faster and simpler, did not appear until the early 1850s. The sounder probably would have been introduced earlier had it not required a new form of specialized labor to decipher the code. Skilled operators using the sounder would eventually attain an average operating speed of twenty to twenty-five words per minute, and were in great demand by the early 1850s. Other noteworthy technical refinements in the 1850s were also made relative to cost efficiency. Less expensive iron wire replaced copper, sturdier and more durable cedar poles coated with wax to prevent rotting were preferred over others, and the Grove battery was the successor to a host of less efficient predecessors.[13]

Innovation in the Structure of Telegraph Firms

The introduction of the key transmitter and the sounder in telegraph offices led the way to productivity increases that follow from refining the organization of the workplace. Telegraph offices from the late 1840s on were operated in a manner similar to the branch offices of a bank. Messages were taken, picked up or delivered, and payment was settled at a cashier window. Operators were usually stationed out of sight in another office, either above or adjacent to the clerical office. Several or dozens of operators were employed, depending on traffic along the route. Separate office managers supervised the clerical and operator offices, and they in turn reported to a branch manager. Local office operations were overseen by a company officer with a management staff that coordinated, controlled and evaluated the activities of the separate operating units.

The first telegraph installations were carried out by companies financed by private investors and licensed by Morse. The managerial expertise of certain figures proved as important as engineering and scientific know-how in diffusing this epoch-making invention. Amos Kendall, a former Postmaster General who had a working knowledge of trunk line postal routes servicing the country, became the principal agent for the Morse patents in 1845. Kendall developed and implemented a plan to interest private capital in investing in telegraph lines along these routes, which had New York City at the hub. The first of these routes connected Wall Street to the Merchant's Exchange in Philadelphia by Autumn of 1845.[14]

In 1846, nine separate telegraph companies had in operation or planned lines to connect Maine to New Orleans.[15] Local financiers would capitalize a telegraph company, obtain a license from Kendall, and then retain subcontractors to build the connecting lines. Even though the cost of construction was about $150 per mile, the annual receipts of the Magnetic Telegraph company, the largest among them, grew from $4,228 in 1846 to $32,810 in 1847.[16] Consequently, by 1850 there was intense competition among such firms along the New York to Washington, New York to Boston and New York to Buffalo routes. But the infant industry was plagued by management redundancies, duplicate service, and an inability to remedy problems with transmission.[17] Service related problems did not, however, reflect operating costs for the lines owned by one company. Instead, the main problems pertained to coordination between and among competing companies—especially the transfer of messages across company lines. The uncertainties in message transfer led to public skepticism and a general reluctance to use the telegraph for long distance communication.[18]

In an effort to overcome these intra-industry problems, Kendall organized and convened the American Telegraph Convention in Washington in March, 1853. The American Telegraph Confederation was created to secure "harmony of interests, uniformity in methods of business transaction, and cooperation in insuring fair rates."[19] But the Confederation was weak from the beginning, especially on account of the war being waged for western supremacy by the New York and Mississippi Valley Printing Telegraph Company, which had been organized by Hirman Sibley in Rochester, New York in 1851 with $83,000 from thirteen Rochester investors.[20] From the outset Sibley aimed to provide continuous service throughout the West to undercut the prevalent practice of transferring messages between competing interests and charging a fee for every transfer.

In 1853, the two-year old New York and Mississippi Valley Printing Telegraph Company possessed a single line that connected Buffalo, Cleveland, Columbus, Dayton and Louisville. What transpired between 1853 and 1856, when the company reincorporated as Western Union, was remarkable in the pace of both line construction and consolidation of local providers. Sibley contracted railways to install new lines, and existing lines in the possession of financially unstable local competitors were purchased outright, or leased. By its inventive use of leasing where it did not build, the New York and Mississippi Valley Printing Telegraph Company undersold potential competitors on long distance routing through its continuous line service.

When it reincorporated as Western Union in 1856, the firm was the largest in the nascent industry and consisted of 132 separate company offices.[21] In the next ten years, by continuing its consolidation campaign, by reinvesting profits into replacing and maintaining older lines, and by its collaborations with railroads, Western Union grew to 2,250 local offices with over 76,000 miles of wire and a total capitalization of

$24.2 million. By 1875, the company maintained 6,565 offices, with 179,000 miles of wire, and was capitalized for $54.7 million.[22]

Technical and Social Links: From the Telegraph to the Incandescent Lamp

The commercial success and growth of the telegraph clearly rested on a technical and social organizational process which standardized the product into, as Alfred Chandler has suggested, one service, one type of traffic, and one set of operational rules and regulations.[23] Such uniformity and regularity in service ultimately prevailed through the organizational standards of Western Union. Even as the rapid expansion of the service progressed, the technical components of the telegraph remained essentially unchanged for forty years.

Equally interesting was that the telegraph maintained its position during this period as the only commercially introduced invention which utilized the scientific principles of electromagnetic induction. The process of innovation in the electrical distribution system for the telegraph is noteworthy in that the sequential development of electric distribution systems for incandescent lighting also had its genesis in electromagnetic induction. What essentially differs in the incandescent lamp beyond more complicated technical refinements in the transmission and regulation of current is the source of the current. Where a battery would suffice for the telegraph, it would not power an equivalent system, on a similar scale, for arc or incandescent lighting. The dynamo and wound armature generator thus have their origins in a process of technical change that would eventually lead from the telegraph to the incandescent lamp.

The possibility for commercially generating efficient, low cost electric current emerged simultaneously with the convergence of technical solutions to problems pertaining to electric lighting. The dynamo, a wound armature motor that generated constant current at voltages far exceeding what the largest batteries had produced previously, was the key link in connecting the principles of telegraphy to electric lighting. By 1872, Edward Weston, a New York chemist, was constructing dynamos from electromagnets for use in electroplating. Five years later the Weston Dynamo Electric Machine Company was organized, with an authorized capitalization of $200,000, and arc lighting had reached a commercial stage of development.[24]

Arc lighting, which had originated in Europe during the 1850s, developed rapidly in the period between 1877 and 1880.[25] Technical know-how in arc lighting and dynamos was closely related, and the commercialization of both technologies was ushered forward by several important firms. These companies were generally organized by urban capitalists who retained the services and patents of an innovator to produce the necessary apparatus for dynamos and arc lights. In this manner Charles Brush was contracted by the Telegraph Supply Company of Cleveland in 1877 and Thomson-Houston, an imitating company, was formed by a group of New Britain, Connecticut financiers to use the technical services and patents of Elihu Thomson of Philadelphia. The Brush Company and the Thomson-Houston Company quickly became the leading producers of arc lights, and each aggressively encouraged local companies to form under their patent licenses.

Brush's first arc light system consisted of dynamos capable of driving two or four lights. Each light was connected to a separate circuit, which created a technical limitation in that the entire system failed if one lamp short-circuited. Unit cost per lamp was high, due largely to labor-intensive armature winding and the high copper content of the lamp. Reductions in operating costs clearly rested on increasing the lighting capacity of each dynamo. This meant running more lamps off a single dynamo, and by 1879 Brush had succeeded in developing a sixteen lamp dynamo for arc lighting.[26]

The increase of capacity by putting more lamps in operation, and three additional innovations, marked the end of technical progress in arc lighting until the early 1890s. The first of these innovations was the double carbon lamp, which furnished light for an average of sixteen hours before it required attention. Second, an automatic regulator for the dynamo maintained a constant flow of current, which kept the remaining lamps lit after a lamp short-circuited. The third innovation was the copper plating of lamp carbons, which provided better contact, decreased resistance, and improved intensity in the lamp itself.[27]

Still, by the end of 1880 only about 5,000 Brush arc lamps and dynamos were in operation throughout the United States; and most were in use for municipal street lighting in large cities.[28] Arc lights were costly and complicated to operate, and the effort to lower unit costs of operation by adding more lamps to a single electrical source pointed to a system which could surmount the limitations which made the arc light impractical.[29] This, of course, was the incandescent lighting system being devised by Thomas Edison during the same three year period from 1877 and 1880.[30]

Invention and Innovation in Firm Structure: The Incandescent Lamp

Given the sequential process of technical change outlined, it is noteworthy that Edison's first inventive contributions were for the telegraph. These date from when, as an telegraph operator, he devised a repeating instrument which enabled a message to be transmitted by one operator over several lines. In 1874 he invented the quadruplex system, which made it possible for four different currents to transmit over one wire simultaneously, quadrupling existing capacity. Edison also made refinements to the stock ticker, which increased the transmitting speed of quotations and, implicitly, trading transactions. These and other cost reducing technical refinements improved the efficiency of the telegraph, and provided Edison with a reputation, before his better known inventions. An important result of this earlier renown was that when he turned his attention to developing a practical system of incandescent lighting, Edison had little difficulty in securing the capital necessary to carry out his experiments.

Beyond the romantic rendition of the Edison as-leading-inventor story rests another story that acknowledges the qualitative change that had taken place in the process of innovation as it became institutionalized within firms. In the case of Western

Union, the technical and social dimensions of innovation refined the practical mechanism of the telegraph, and the organizational structure of the firm followed. In the progression of applying electromagnetic induction to the incandescent lamp, previous innovations in industry organization and firm structure were adapted to the inventions of Edison, who concentrated his efforts on the technical problems of invention.[31]

Unlike the telegraph and Western Union, the organization and financing of the Edison Electric Light Company of New York in October, 1878 preceded the successful development of a practical incandescent lamp. A group of New York financiers, led by Egisto Fabbri, a J.P. Morgan partner, and Norvin Green, the president of Western Union, put up $300,000 to capitalize the company.[32] From these sources Edison obtained a total of $490,000 in capital between 1878 and 1884 for expenses related purely to the technical development of the incandescent lamp. The actual manufacture of the electrical components of the electrical system for the lamp was financed and carried out under separate Edison companies that were created to manufacture the necessary components of the system.

The incandescent lamp was powered by dynamos which, in the beginning, were basically the same size and efficiency as those used for the arc light. By 1880, three additional Edison companies were manufacturing dynamos, underground circuits, wire, fuses, sockets, junction boxes, meters, and other electrical apparatus for incandescent lighting. That year, the first experimental installation of lamps was made in the community around the Menlo Park, New Jersey lab. Public and financial interest had increased to the point where the formation of local Edison companies in other communities was discouraged until every aspect of the entire system had been carefully tested, checked and refined.[33] In this case, the market was clamoring for the invention.

Accounts of the construction of the first commercial service district in the Pearl Street area of downtown Manhattan attest to the cautious, well-marketed plan of Edison's financial and managerial associates. The Edison Electric Lamp Company first took a marketing survey of the Pearl Street area to determine whether gas jet users would switch to the incandescent lamp if the company furnished the service at the same cost as the gas companies. All but 850 of 16,000 homes and businesses responded favorably. The installation in the Wall Street area, carried out in 1882, was much like an experiment, with refinements made in every aspect of production, distribution and marketing as results required. It was overseen by an entirely new corporate organizational structure of skilled technical field personnel including engineers, draftsmen, designers, lab technicians, technical supervisors, chief inspectors, production supervisors, methods analysts, quality control analysts and salesmen. Previously Edison had maintained a well-compensated lab staff which used its scientific knowledge to duplicate and improve upon any innovation introduced in the development of the incandescent lamp. But by 1882 the associated Edison companies were completely integrated into all aspects of technical innovation and development in electrical incandescent lamp systems.[34]

Conclusion

What results are suggested by the sequential process of innovation that runs from the telegraph to the incandescent lamp? From the perspective of the technical changes that occur in creating the inventions there is, explicitly, a progression from simple to increasingly more complex systems. This is closely associated with the change in the generation of power between the battery generated telegraph and the dynamo generated arc light. The telegraph and arc lighting systems were otherwise technically similar electrical systems; both are uncomplicated circuits of constant current which did not require system controls outside of simple electromagnetic relays and transformer devices. But the development of the dynamo, which emerged simultaneously with arc lighting, made it possible to generate the electricity needed to commercially operate a number of lighting circuits off of a single source of current. Just as importantly, the dynamo led to subsequent refinements which resulted in a more technically complex system of control devices for the current, especially as attempts were made to increase the number of lights per dynamo.[35] This, in sequence, led to the development of the incandescent lamp through an effort to lower unit costs of operations in arc lighting that would come via the addition of more lamps.

The parallel electrical network of the incandescent lamp was certainly much more complicated, especially with its three wire and feeder main distribution technique, than the single wire, single current of the telegraph and simple arc light.[36] Only through the technical refinement of the incandescent lamp were fuses, switches, metering devices, junction boxes and other associated apparatus invented as essential technical components of the system. Technical change in electrical systems from the simple telegraph to the complex incandescent lamp can thus be viewed as a sequential process which yields results and trends that are obtained and specified through the process itself. But these results and trends were not just technical.

The sequential movement from the telegraph to the incandescent lamp progressed alongside the social organizational development of institutions to design, manufacture, install, market and service new products. This organizational dimension of the sequential process of innovation led to consolidation, centralization, internal control, capital accumulation and the reinvestment of profits in the case of Western Union, and pointed toward a more extensively integrated managerial process of the same type in the case of the Edison Electric Company.

In addition, the process of innovation generated competitive markets which resulted in technical and social organizational refinements in the firm which lowered unit costs of production and led to standardized products that were widely diffused.[37] In this manner market pressures simplified the key transmitter and sounder in the telegraph, as well as institutionalized the one service, one type of traffic and one set of operational rules and standards in the form of Western Union. Likewise, the increase of scale made possible by the dynamo was associated with both the development and consequent refinement of all technical aspects of electric lighting, first in arc and then in incandescent, as well as pointing toward a process of integration into all phases of the creation, production and distribution of these new products.

Finally, the sequential process of innovation outlined in this paper suggests a process that nurtures and sustains technical knowledge, invention and diffusion throughout the firm. It hence becomes a process that assumed an increasingly integrated character relative to technical change, social organization within the modern American corporation, and the generation of markets. Accordingly, we should view the causes of this process as inseparable from its effects if we investigate other instances to gain a richer insight into the sequential process of innovation.

Notes

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1. On the importance of scientific principles leading to technical innovation, see John Jewkes, David Sawers and Richard Stillerman, *The Sources of Invention* (New York: W.W. Norton and Company, Inc., 1969), 49.

2. Alfred Chandler, *The Visible Hand: The Managerial Revolution in American Business* (Cambridge: Harvard University Press, 1977).

3. Perhaps the earliest conceptual account of an electric telegraph appeared in an anonymous letter to Soot's Magazine in England in 1753. Entitled "An Expeditious Method of Conveying Intelligence," the letter described a system of lines between two points put into communication by electricity. There is one wire for each letter, which terminates in a pith ball that lifts a piece of paper when the opposite end of the wire is connected to a frictional electric machine. See E.A. Marland, *Early Electrical Communication* (London: Abelard-Schuman Ltd., 1964), 17.

4. Marland, *Early Electrical Communication*, 30.

5. Soemmering's telegraph closely resembles the conceptual scheme of the instrument described in the letter to Soot's Magazine over fifty years earlier. See Marland, *Early Electrical Communication*, 36.

6. Henry would later become the founding Secretary of the Smithsonian Institution. He frequently wound wire of many miles in length around the Institute building for his experiments. Henry probably does not have the reputation he should have because he did not file patents for his electrical discoveries. Patents, at that time, were usually filed for mechanical or manufactured devices.

7. Morse's code was worked out from a careful study on the frequency with which letters were used in communication. "E", the most frequent, is represented by a dot; "T", the second most frequent, by a dash. See Marland, *Early Electrical Communication*, 134.

8. Indeed, Morse has been characterized as "almost entirely ignorant of scientific matters." See Marland, *Early Electrical Communication*, 129.

9. The willingness of the federal government to finance the first test of the telegraph is noteworthy. This is the first instance, aside from the postal service, of federal investment in the communications infrastructure of the developing national market. The federal government previously had a long-standing role in financing internal improvements for transportation infrastructure. See my *Opening the West: Federal Internal Improvements Before 1860* (Westport, Connecticut: Greenwood Press, 1998).

10. The demand for wire increased dramatically following the introduction of the telegraph, which led to improvements in the methods and scale of its manufacture. See Victor Clark, *History of Manufactures in the United States, Volume II: 1860 to 1893* (New York: McGraw-Hill, 1929), 94.

11. Phil Ault, *Wires West* (New York: Dodd, Mead and Company, 1974), 16.

12. Robert Luther Thompson, *Wiring A Continent: The History of the Telegraph Industry in the United States 1832-1866* (Princeton: Princeton University Press, 1947), 26.

13. Thompson, *Wiring a Continent*, 248.

14. Thompson, *Wiring a Continent*, 41.

15. Thompson, *Wiring a Continent*, 191.

16. U.S. House of Representatives, *Report of the Superintendent of the Census*, (December 1, 1852) (Washington: Robert Armstrong, Printer, 1853), 107-108.

17. Thompson, *Wiring a Continent*, 187.

18. The telegraph was also used for communications within firms. The largest factory in Philadelphia, in 1854, employed 700 operatives in separate buildings connected by one such system. See Victor Clark, *History of Manufactures in the United States, Volume I: 1860-1893* (New York: McGraw-Hill, 1929), 527.

19. Thompson, *Wiring a Continent*, 260.

20. Thompson, *Wiring a Continent*, 268.

21. Chandler, *The Visible Hand*, 198, outlines the extent of the Western Union management structure in 1856. The corporate headquarters had a legal staff, repair and maintenance managers, auditors, purchasing agents, electricians and laboratories for testing and developing equipment, and a full management staff for two factories that produced "every variety of instrument required in the service."

22. United States Department of Commerce, Census Bureau, *Historical Statistics of the United States: Colonial Times to 1970* (Washington: US Government Printing Office, 1975), 788.

23. Chandler, *The Visible Hand*, 189.

24. W. Paul Strassmann, *Risk and Technological Innovation* (Ithaca: Cornell University Press, 1959), 161.

25. Arthur Bright, *The Electric Lamp Industry: Technological Change and Economic Development From 1800-1947* (New York: The MacMillan Company, 1949), 30-32.

26. Harold C. Passer, *The Electrical Manufacturers, 1875-1900* (Cambridge: Harvard University Press, 1953), 17.

27. Passer, *The Electrical Manufacturers*, 18.

28. Passer, *The Electrical Manufacturers*, 20.

29. Arthur Bright attributes the development of the incandescent lamp to attacking, "the subdivision of the electric light," given the limitations of arc lighting. See his *The Electric Lamp Industry*, 41.

30. Useful contemporary accounts of Edison's efforts are found in: Algrave E. and J. Boulard, *The Electric Light: Its History, Production and Applications* (New York: D. Appleton and Co., 1884); Edwin Houston, *Electric Incandescent Lighting* (New York: W.J. Johnston Company, 1896); and Franklin Pope, *Evolution of the Electric Incandescent Lamp* (Elizabeth, New Jersey: Henry Cook, 1889).

31. Passer, *The Electrical Manufacturers*, 360-61.

32. Passer, *The Electrical Manufacturers*, 84-88.

33. Bright, in *The Electric Lamp Industry*, 58-60, provides an account of the level of public and financial expectation concerning Edison's efforts to develop an incandescent lamp in the period between 1878 and 1880. Bright cites an interview given by Edison to the New York Tribune on September 28, 1878 in which he said: "There is no difficulty about dividing up the electric currents and using small quantities at different points. The trouble is finding a candle that will give pleasant light, not too intense, which can be turned on or off as easy as gas." Edison's claim immediately aroused public and scientific interest and precipitated a brief crisis in gas company stocks.

34. Bright, *The Electric Light Industry*, 70-72.

35. Nathan Rosenberg, "The Direction of Technical Change," *Economic Development and Cultural Change*, (October 1969) 4.

36. Passer, *The Electrical Manufacturers*, 360.

37. W.E.G. Salter, *Productivity and Technical Change* (London: Cambridge University Press, 1969).