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Technology Adoption, Standardization, and Lock-In in the 19th Century U.S. Telegraph Industry

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Abstract

The paper examines the economic forces that influenced technology adoption and diffusion in the American telegraph industry. Reviewing the history of innovation, standardization, and consolidation in the U.S. telegraph industry in the nineteenth century, attention is drawn to institutional factors and technological lock-in that perpetuated inefficient ways to transmit telegrams.

Keywords: telegraph, standardization, network effects, lock-in, Morse code
JEL codes: L15, N81, O33

Ⅰ. Introduction

The introduction of the electromagnetic telegraph in the United States in 1844 spawned the telecommunications industry and profoundly influenced the development of the American economy in the late nineteenth century. Alfred Chandler, in his seminal work *The Visible Hand*, places the telegraph and the railroad center-stage as technologies essential to engendering high-volume production and distribution and developing the first large-scale, highly coordinated business enterprises.[2] The telegraph industry, as one of the classical "network industries," was characterized by positive coordination externalities accruing to participating economic agents - telegraph firms, telegraph operators, and telegraph users. During the decade following the erection of the first telegraph line, the industry underwent explosive growth in the geographical extent of its wire network and in the number of independent firms operating telegraph lines. Concomitant with the early growth of the industry was the emergence of the Morse telegraph as the industry standard, which went on to form the technological backbone of the industry until well into the twentieth century. The process of technological standardization was accompanied by a somewhat slower, yet equally inexorable transformation of the industry towards horizontal integration and eventual internalization of network externalities by a powerful monopoly.

Formal modeling of standardization in the presence of network externalities has received substantial attention in the economics literature (*e.g.,* see Arthur 1989, Farrell and Saloner 1985, Katz and Shapiro

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1） Faculty of Economics, Gakushuin University, Tokyo, Japan.

2） Chandler (1977), p. 79

1985). Economic history literature includes case studies of standardization in other network industries which, like the telegraph, were also at the center of late nineteenth and early twentieth century U.S. economic development: electricity supply (David and Bunn 1988), railroads (Puffert 1991), and typewriters (David 1985). The impact of the telegraph on the American economy has been studied by Field (1992) and DuBoff (1983), although without focusing on standardization.

The purpose of this paper is to come to a better understanding of the economic forces underlying the pattern of technology adoption in the American telegraph industry during the nineteenth century. The approach taken is to highlight standardization aspects of the history of the U.S. telegraph industry, draw analogies and distinctions to the other nineteenth century network industries, and examine the extent to which the evolution of the telegraph can be placed within the current theoretical framework of standardization in the presence of network externalities.

The paper finds that the network externalities inherent in telegraph technology serve an important role in explaining the historical pattern of industry development and technology adoption. The economic history of the emergence and persistence of the Morse standard in the U.S. telegraph industry provides insights into the dynamics of standardization in network industries in general. Furthermore, the particular aspects of early telegraph technology as well as the contemporary institutional setting provide an interesting opportunity to test the applicability of current models of the economics of standardization.

It is the nature of the specific constraints inherent to a particular network technology, viewed in the context of the particular economic and institutional conditions surrounding its adoption, that leads to the fullest understanding of the history of a network industry. Nevertheless, it is useful to first draw upon theoretical formulations to consider some of the identifiable features characterizing the adoption of network technologies in general. Section II thus reviews the relevant economics literature and distills a set of general concepts and characteristics used in subsequent sections. Section III summarizes the feasible alternatives offered by nineteenth century telegraph technologies. The history of consolidation and standardization in the U.S. telegraph industry is related in Section IV. Section V attempts to establish an economically rational connection between the technological possibilities and historical reality by examining the roles of institutions, demand for telegraph services, and production-side network externalities. Section VI compares the network characteristics of and evolutionary path in the telegraph industry to those in railroad, electricity supply, and typewriter industries. Further areas of inquiry and conclusions are summarized in Section VII.

Ⅱ. The economics of evolution of network industries

The dynamics of technology competition and adoption have been a focus of much scholarship. A number of theoretical models with rather surprising, if not disturbing, results have been advocated and several historical case studies have been carried out documenting many of the phenomena predicted by the theory.

Widespread adoption of a new technology to the virtual exclusion of competing technologies has been shown to result under increasing returns to adoption. Increasing returns often characterize technology adoption since the returns to adopting a particular technology relative to adopting one of the contenders increase with the number of agents already using the technology. The two main reasons for this increase are learning by doing and reduction of uncertainty.[3] Learning by doing describes the gradual perfection of a technology as operational experience accumulates. Reduction of uncertainty refers to the gradual revelation of the true merit of an initially uncertain technology that accompanies its use in the field. Both effects are self-reinforcing since they tend to increase the attractiveness of today's most adopted technology to those deciding which technology to adopt for use tomorrow.

Arthur (1989) developed a model of sequential, decentralized, stochastic technology adoption process in the presence of increasing returns. His model shows that several outcomes are possible, the exact sequence of adoption events can play a pivotal role in determining which technology prevails in the long run, the outcome of this *path-dependent* process is unpredictable *a priori*, and after a short initial window of time, one of the competing technologies becomes *locked-in* and the rest become *locked-out*. Furthermore, there is no guarantee that the locked-in alternative is superior to the ones that are locked-out. Cowan (1991) showed that, in addition, the market undersupplies experimentation to reduce uncertainty about the relative merits of competing technologies, biasing the adoption process in favor of earlier and more popular technologies, rather than superior ones.

Increasing returns to adoption stemming from learning by doing and reduction of uncertainty underlie the adoption of most technologies. However, in the special case of network technologies, an additional powerful source of increasing returns is present due to network externalities. David (1987, p. 208) defined a "network technology" as characterized by *technical interrelatedness* among its constituent components and *economies of system scale* or, in other words, *network integration benefits*. Technical interrelatedness further cements lock-in by raising the costs of changing away from the adopted technologies — it costs more to introduce and coordinate a change in the technology if its components are tightly coupled throughout the network. Economies of system scale also work to reduce variety by encouraging coordination, often even consolidation of operations, across the network in order to realize the benefits from positive network externalities or avoid bearing the costs of negative ones. Carlton and Klamer (1983) stressed the importance of horizontal integration for internalizing network externalities and subsequent vertical integration into research and development for avoiding freezing the technology at "the lowest common denominator."

Farrell and Saloner (1985) showed how easily an industry with network externalities can lock-in to a suboptimal standard. Assuming the industry has adopted a standard in the past and is faced with a new, superior standard, their model shows that perfect information leads the industry as a whole to switch to the new standard even when firms are deciding sequentially, in a decentralized fashion. However, under incomplete information regarding the desire of each firm to switch, the model shows that "inefficient inertia" can easily develop when the firms most in favor of switching are not sufficiently eager to switch first. A "bandwagon" fails to be started and the industry does not switch even though doing so would bring total benefits exceeding total costs.

Well-defined intellectual property rights and the resultant "technology sponsoring" can affect the

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[3] Cowan (1991), p. 807

dynamics of technology adoption. Katz and Shapiro (1986) demonstrated that if only one of two competing technologies is sponsored, it carries a strategic advantage and may be adopted even if it is inferior. But, their model also shows that in the case of both competing technologies being sponsored, the one that is perceived to be better in the future is likely to be adopted as the standard.

The conceptual framework which emerges from the literature underlines the inadequacy of the decentralized price system for optimizing standardization processes and reinforces the importance of events of an essentially historical nature in determining the dynamics of technology adoption.

Ⅲ. Feasible alternatives among telegraph technologies

The Morse system of telegraphy was first demonstrated in 1837 and quickly became the dominant telegraphy standard in the United States and around the world. Morse telegraphy remained prominent into the 20th century, often symbolizing the very essence of telegraphy. Yet Morse's design was neither the earliest nor the only electric telegraph system to be proposed or deployed. In fact, early technical literature on telegraphy lists dozens of different electric telegraph systems invented during the first half of the 19th century. One authoritative source counts about 62 inventors who claimed discovery of the electric telegraph prior to 1838.4) A design by one Samuel Soemmering even dates back to 1809.5) However, of the numerous proposed telegraph systems, only five came to be commercially deployed in notable numbers in the United States during the first twenty five years of the industry: the Morse Electromagnetic Telegraph, the Bain Electrochemical Telegraph, the House Printing Telegraph, the Hughes Printing Telegraph, and the Phelps Combination Printing Telegraph.6) Nineteenth century telegraphs can be classified into three categories: manual, printing, and automatic.

Among the early electric telegraphs including those never deployed, the manual Morse telegraph stood out as the simplest. It required a circuit, batteries, a transmitting device capable of opening and closing the circuit (Morse key), a receiving device capable of producing audible beeps (Morse sounder) or line markings on paper (Morse register) corresponding to the opening and closing of the circuit, a code assigning each letter of the alphabet and each digit a unique sequence of dots and dashes (Morse code), and two operators. A message was transmitted via the Morse telegraph by one operator manually punching the Morse code representation of a message using the Morse key, and a second, distant operator transcribing back into the English alphabet the dots and dashes as he heard them coming from the Morse sounder. A typical operator pair could transmit 25 to 40 words per minute.7)

Much effort has been devoted toward inventing and perfecting printing telegraphs which could mechanize the encoding, decoding, and writing functions that were performed manually in the Morse system. Three main technological innovations were necessary to build a printing telegraph. First, it was necessary to build a convenient input device allowing the sending operator to enter the text of the

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4) Reid (1879), p. 110

5) Shaffner (1867), p. 142

6) Prescott (1860), p. 230

7) Maver (1903), p. 336

message to be transmitted. Second, it was necessary to invent an apparatus capable of marking arbitrary sequences of characters on paper and automatically advancing the paper. Finally, the input and printing devices had to be synchronized and enabled to communicate with each other. The input device problem was the easiest to solve: piano keyboard designs were adapted for text entry by marking the keys with letters of the alphabet. The printing apparatus and synchronization, however, proved difficult to overcome and required a series of breakthroughs and years of incremental design enhancements. The first two types of printing telegraph to be deployed, the House and Hughes telegraphs, suffered from lack of reliability. The Phelps telegraph, perfected in 1859, borrowed the best design features of the House and Hughes systems and offered a twice-as-fast, reliable, labor-efficient alternative to the Morse system.8) A subclass of printing telegraphs was specifically designed for operation on telegraph lines leased to firms in other industries. These telegraphs, such as the popular Gray Printing Telegraph introduced in 1871, were slower, but more compact and easier to use by untrained operators.

The large disparity between the rate at which information could be transmitted electronically and the rate with which text could be entered manually was also realized early. Whether punching Morse code or typing on a keyboard, human operators were confined to rates of well under 100 words per minute. The so-called automatic telegraphs were able to achieve transmission speeds of hundreds of words per minute by decoupling the transmission function from text entry and transcription functions. In automatic telegraphy, messages were manually encoded into machine-readable form (such as perforated paper tape), which served as input to a high-speed transmitting apparatus. On the receiving end, a high-speed receiving apparatus decoded and printed the text. The Bain telegraph of the late 1840’s was the first automatic telegraph. However, the lack of an appropriate mechanism for preparing perforated forms led the early Bain lines to abandon the automatic mode of transmission and resort to using a conventional Morse key to manually encode and transmit the messages.9) By the late 1870's, the American Automatic Telegraph perfected by Edison and the Wheatstone Automatic Telegraph were able to offer transmission rates an order of magnitude faster than human operators keying Morse code or typing on keyboards. However, since the same operator effort was required to prepare the machine-readable copy of the messages as was required to transmit it using a printing telegraph, the advantages afforded by automatic telegraph technology lay primarily in raising the productivity of capital embodied in the wire network rather than raising the productivity of labor.

Another method for raising the productivity of capital embodied in the wire network involved the use of duplex and quadruplex methods for simultaneously transmitting several telegrams across a single wire circuit. The quadruplex method, which became practical around 1875, enabled the transmission of four simultaneous telegrams, two in each direction. It was preceded by a few years by the duplex method which allowed a doubling, rather than quadrupling, of telegraph traffic across a single wire. Compared to automatic telegraphs, duplex and quadruplex used in conjunction with Morse telegraphy represented a simpler means of raising wire capacity and engendered significantly less change in operations.

8） Prescott (1860), pp. 149-55 and Prescott (1885), p. 647

9） Prescott (1885), p. 693

Ⅳ. History of technology adoption and industry evolution

In the span of twenty-five years, American telegraphy underwent a transformation from an incipient stage characterized by technological diversity and industrial disorder to a standardized network coordinated by a powerful monopoly.

A. From chaos to an industrial order in the telegraph business

"A mad era of methodless enthusiasm" is how telegraph historian Robert L. Thompson describes the first years in the nascent telecommunications industry.10) He goes on to recount the precipitate expansion of the U.S. telegraph network following Samuel F. B. Morse's demonstration of instantaneous communication between Baltimore and Washington in May, 1844. By 1852, over 23,000 miles of wire strung by some 30 different telegraph companies connected most of the principal urban areas east of the Mississippi.11) The majority of the telegraph companies were beset with problems including unreliability of service, poor management, and unstable finances. Cooperation among industry players was practically nonexistent, as can be inferred from the following account of the condition of the telegraph industry in 1851, relayed a quarter of a century later by Morse's biographer:

> ... the great number of separate lines in operation prevented that unity and dispatch in conducting the business so essential to its success, and the public failed to secure everywhere the benefits of direct and reliable communication. Telegraphic correspondence between the Eastern, Western, and Southern sections, was not only burdened with several tariffs, but with unnecessary delays. Messages under this system required copying and retransmission at the termini of each local line, and this process not only occupied time, but was frequently the cause of errors, which rendered the service of little value.12)

Furthermore, each individual telegraph company refused to assume the risks of transmission beyond its own wire network, resulting in a system "... rank with dissension, and distrust, and danger."13)

Despite these serious problems, wire network growth continued accelerating: the Pacific coast was connected to the eastern United States in 1861, and by 1866 U.S. wires totaled 88,000 miles in length.14) Amidst this backdrop of continued expansion, the initial chaos was beginning to be overcome by technological standardization and industrial consolidation. Cooperation and consolidation in the U.S. telegraph industry began in earnest in 1853 at the first American Telegraph Convention where representatives of 16 telegraph companies met to discuss issues of mutual interest including that of

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10) Thompson (1947), p. 97

11) Thompson (1947), p. 240

12) Prime (1875), p. 586

13) Reid (1879), p. 427

14) DuBoff (1983), Table 1, p. 256

taking responsibility for transmitting messages originating on other companies' lines.15) The convention became an annual event, and eventually led to the 1857 "Six Nations' Alliance" agreement entered into by six powerful telegraph companies operating Morse telegraph lines, effectively dividing U.S. territory east of the Mississippi into six mutually exclusive regions. Each party to the agreement promised to do business exclusively with the other parties and work to either consolidate with or otherwise eliminate competition in its region of operation.16) The members of the Six Nations' Alliance proceeded to organize themselves as the North American Telegraph Association, attract several other major telegraph companies into their union, and secure the rights to all of the key telegraph patents of Morse, House, Hughes, and Bain.

The stability of this cartel was undermined by the ambitions of its members. A bitter rivalry, interrupted only by the Civil War, resulted in the emergence of Western Union Company as a monopoly in the U.S. telegraph industry. Although the absorption of small and large competitors by Western Union continued throughout the 1870's and 1880fs, monopoly power was effectively in its hands starting in the late 1860's.

During the 1870's and 1880's, the business of leasing out telegraph lines to companies in various sectors such as financial services, retailing, and the press grew and approached regular telegraph service in terms of profitability.17) Western Union engaged in leasing out some of its lines while bringing under its control the burgeoning "local" telegraph companies specializing in leasing. Most notable among such companies was the Gold & Stock Telegraph Company which focused on New York banking and brokerage markets and pioneered during the early 1870's ticker tape reporting of New York Stock Exchange prices transmitted via local telegraph wires.

The lessee firms as well as the other companies sending telegraphs through the main telegraph network found it advantageous to adopt word-level codes to reduce communication costs. These codes mapped English words and phrases into shorter artificial words. Many of the codes were carefully produced by specialized code publishing companies. Some codes were for general use, others were industry-specific or even company-specific.18) Specialization occurred among Morse operators who worked in a single sector with its characteristic code and vocabulary: "a commercial operator would be 'lost' in a yard office, or the train dispatcher in taking markets."19)

Since the unnatural combinations of letters appearing in coded messages slowed down Morse operators, a prolonged game ensued between Western Union and other telegraph companies around the world on one side and business users and code makers on the other. The game, which took on an especially serious and international character in the first three decades of the twentieth century, involved the telegraph companies changing tariff structures to reflect the additional value and expense of transmitting coded words and code makers, and code-using companies changing their codes to best adapt to new rate structures. Higher tariffs were assessed for coded words than for plain words, while elaborate rules proliferated attempting to define the blurry line between a coded and a plain word.

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15) Reid (1879), p. 428-9

16) Thompson (1947), p. 314-7

17) DuBoff (1983), p. 268

18) Friedman (1928), pp. 39-40

19) Bryan and Harter (1897), p. 29

B. Standardization in the telegraph industry

During the first twelve years of the American telegraph industry, only three different telegraph technologies were deployed. The Morse telegraph was first deployed in 1844 between Baltimore and Washington under a $30,000 federal contract solicited from the Congress by the inventor himself. The House printing telegraph was introduced in 1848 between New York and Philadelphia, followed by the Bain automatic telegraph, which was first put into service in 1849 between Louisville, Kentucky and New Orleans.20)

The Morse telegraph leveraged the advantages of an early start and simplicity of design into a substantial lead over its rivals: it was used on 83% of the wires in operation in the U.S. in 1850 and on 77% of the wires in 1852.21) After 1852, despite the technological progress and the resulting availability of technological alternatives, the relative share of Morse telegraph deployment grew to a virtually complete dominance, which it retained into the twentieth century, when automatic telegraphs began being introduced in earnest on the busiest U.S. lines.22) The factors which contributed to emergence of the Morse telegraph as a dominant standard were its operational superiority, lower capital requirements, early head start, aggressive sponsorship, and luck.

The simplicity of the Morse telegraph allowed it to operate reliably over wires of varying and poor quality which long characterized much of the American network.23) Reliability of service was important to overcoming skepticism among potential users and reaching a profitable scale of operation. The simplicity also translated into comparatively small capital layouts and recurring maintenance costs for both the wire network and the telegraph equipment. Furthermore, the simple design of the Morse telegraph made it the only contemporary telegraph technology which could be economically operated for low-volume, sporadic communication characteristic of railroads and numerous small towns becoming part of the expanding telegraph network.24)

As with most new technologies, learning by doing played a significant role in improving the Morse telegraph as its deployment spread. Thanks to an unexpected interplay between a side-effect of the implementation of the Morse register and human psychology, the Morse telegraph which came to be widely deployed differed in a significant way from Morse's original, patented design used on the first Morse lines of 1844 -1850. No one anticipated the ability of the human brain to become proficient at aurally recognizing entire words the letters of which were sequentially encoded employing only short beeps, long beeps, and pauses. The failure to anticipate this is why all early telegraph designs provided for exclusively visual means of receiving messages: markings on paper, deflections of needles, etc. It was only by luck that the original Morse register happened to produce an audible sound as a by-product of recording dots and dashes of received Morse code on paper. Early operators received messages working in pairs: one looked at the dots and dashes on the paper strip coming out of the register and

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20) Jones (1852), pp. 78-80

21) Thompson (1947), p. 240

22) Maver (1903), p. v

23) Prescott (1860), p. 231

24) Reid (1879), p. 469 and p. 479

announced the corresponding English words, while the other wrote them out longhand. By 1849 many operators became so accustomed to hearing Morse code that they could recognize words by simply listening. Yet despite the greater accuracy, speed, simplicity, and savings of labor, capital, and maintenance expenses afforded by direct aural transcription, telegraph company managers initially disallowed the "extraordinary feat of receiving by sound" and threatened to fire operators caught practicing it. Within a year, however, the superiority of reading by sound became acknowledged and registers began being laid aside in favor of the much simpler "sounders." From then on, operators were required to transcribe by sound.25)

While the simplicity of the Morse telegraph and the resultant versatility, reliability, and cost advantages were propelling its wide adoption in the early telegraph industry, the drawbacks of manually communicating in an artificial telegraphic code were being recognized. Relying on operators to manually encode, decode, and write out received telegrams engendered two main drawbacks: high intensity of skilled labor input was required and large variance in the overall telegraphic process could not be reduced due to the variability in human skills. Translation from the English alphabet into Morse code, signaling the dots and dashes using the key, decoding the Morse signal, and penmanship were all skills which differed from operator to operator and changed for each operator over time. The printing telegraphs of House, Hughes, and Phelps emerged as attempts to mechanize many of the manual functions in Morse telegraphy. However, the use of the first printing telegraph, that of House, was mostly limited to telegraph companies unable or unwilling to obtain a license to the Morse patent. As the large companies operating under license to the Morse patent were gaining control over the smaller “opposition lines” during the late 1850’s, the few House telegraphs that were in use at the time were being replaced with manual Morse telegraphy.26) The Hughes printing telegraph was first put onto a commercial line in 1856, but was replaced within a few years by the superior Phelps design.27) However, in spite of its reliability and speed advantages, only a few exceptionally busy lines continued using the Phelps telegraph throughout the 1860’s and 1870’s.28)

During the decade of 1870 several important innovations were introduced in the telegraph industry, but with mixed success. In 1875, Atlantic & Pacific Telegraph Co. fully embraced the Edison's American Automatic Telegraph but was soon forced to relegate it to an auxiliary role. The manual Morse system took over because poor connections in the actual telegraph network limited the speed of reliable automatic transmission to about 75 words per minute, which was not enough to justify its use.29) In contrast to the poor performance of the automatic telegraph under actual commercial service conditions, the introduction of duplex telegraphy on Western Union lines in the early 1870’s, soon followed by the quadruplex in 1874, was a success. By 1884, almost all major Western Union links were using quadruplex technology in conjunction with the original, manual mode of Morse telegraphy.30)

25） Thompson (1947), p. 250 and Shaffner (1867), p. 463

26） Reid (1879), p. 470

27） Reid (1879), p. 413

28） Prescott (1885), p. 642

29） Reid (1879), pp. 588-89

30） Prescott (1885), pp. 843-44

As a result of the failure of automatic and printing telegraphs to take root in the U.S. telegraph network, as late as 1907 the Census counted only 1.6% of miles of wire used with "machine or automatic systems, which make possible a higher rate of speed than can be attained by hand."31) Manual Morse telegraphy accounted for the remaining 98.4% of the wires, with the following breakdown: 16.9% quadruplex, 15.2% duplex, and 66.4% single-line circuitry not unlike that originally deployed over half a century earlier. However, counting miles of wire lumps long, lightly used circuits from remote outposts together with high-volume lines between major urban centers and thus understates the degree of automation weighted by volume of traffic. To compensate for this effect, one could consider the single-line circuits to be below the threshold requiring automation and exclude them from the total. The renormalized percentages of deployed-miles of "advanced telegraph technology" then become: quadruplex - 50%, duplex - 45%, and machine or automatic - 5%. Even such re-normalization fails to show a significant acceptance of automatic telegraphy by the industry.

In contrast to the tenuous rate of adoption of automation in the overall telegraph network, printing telegraph technology did take root on telegraph lines which were leased out to private companies. The needs of the lessees, mostly securities brokers, large retailers, press associations, and banks, required simple, fast, confidential, and reliable telegraph operation without much training. The printing instruments specially adapted for use on private lines, the Gray's Printer being a prime example, met such needs well and found quick, widespread acceptance.32)

Ⅴ. Economic and institutional factors influencing telegraph technology adoption and industry evolution

Having examined the characteristics and chronology of feasible alternatives among telegraph technologies and relayed the actual history of technology adoption and industry evolution, it remains to identify and analyze the factors that relate what was possible to what actually transpired. In particular, to understand the history of the U.S. telegraph industry it is necessary to explain its early and strong tendency toward horizontal integration and eventual monopoly, the long interval between the invention and adoption of labor and capital productivity-enhancing technology as a replacement for first-generation manual Morse telegraphy, entrenchment of the telegraph code language, and lack of growth through vertical integration.

A. The role of the institutional framework

Institutions played an important role in shaping the evolution of the U.S. telegraph industry, especially during its early stages. The Morse telegraph enjoyed an early, advantageous start thanks to Samuel Morse's success in 1844 in soliciting federal funds to build the first line. Upon successfully completing

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31) U.S. Bureau of the Census (1909), p. 14

32) Reid (1879), p. 624

the project, Morse tried to sell his proprietary interest in the telegraph to the federal government for $100,000 but the Congress refused, being skeptical of future telegraph revenues.33) Unlike most European governments, the Congress, by refusing to make the telegraph part of the Post Office, left the evolution of telegraph service to market forces.

Patent rights and the results of related litigation had a pronounced influence on the pattern of deployment of telegraph technologies in the U.S. during the first three decades of the industry. Morse obtained a very broad patent to his invention in 1840 and then was able to extend it in 1854 for an additional seven years. The holders of the Morse patent interests even petitioned the Congress to renew the 1840 patent a second time, past its 1861 expiration, but the Congress refused.34)

Morse and those affiliated with his proprietary rights often resorted to litigation not only to fight outright infringements but also as a tactic for impeding the deployment of rival telegraph designs. A great deal of telegraph litigation took place during the life of Morse's patents, especially in the period from 1848 to 1859. One of the cases reached the Supreme Court, which, in 1854, upheld all of Morse’s claims in his patent of 1840 except for one disproportionately broad claim which gave him exclusive use of electromagnetism for recording telegraph messages.35) Alternative telegraph systems were also patented by their inventors and some withstood legal challenges initiated by Morse affiliates.36) In particular, the patents of House, Bain, and Hughes came to carry significant value as a basis for "opposition lines” competing in the industry against Morse licensees.

The patentees typically "licensed" their rights to entrepreneurs by taking an equity position in newly formed telegraph companies in exchange for allowing those companies to use the patented telegraph designs. The license granted to the entrepreneurs was typically limited to specific geographic areas or between specific cities. The licenses often stipulated that such use be exclusive, in the sense that patentees guaranteed the licensees regional monopolies and the licensees agreed not to connect their wires to those of any other telegraph company which was not also a licensee of the same patent.37) This particular licensing structure encouraged the formation of industry camps, each based around one patent and disconnected from the others. If a patent were to suffer a defeat in courts, the corresponding camp would typically seek to merge with companies operating in the same region under a different patent. An instance of this took place when the Bain telegraph (when operated manually without its impractical perforated form feeder) was found in 1851 to be infringing on the Morse patent. Within a year of the court ruling, the Bain lines were totally consolidated with the Morse licensee companies.38)

During the 1850's, the allocation of patent rights changed from a region-by-region process and took on a more industry-wide character. After organizing the Six Nations' Alliance cartel, the six large telegraph companies bought out the rights to the Morse, House, Hughes, and Bain patents and used them to absorb or control hundreds of smaller independent telegraph companies, hastening the consolidation

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33) Prime (1875), pp. 510-11

34) Reid (1879), p. 430

35) Prime (1875), pp. 565-79

36) Prime (1875), p. 582

37) Thompson (1947), pp. 452-71

38) Thompson (1947), p. 194

of the industry.[39)]

Notably absent from the institutional framework was any organization or agency tasked with overseeing or facilitating standardization. The lack of standard-setting institutions and procedures forced early industry players to invent methods of cooperation along the way.

B. The role of demand for telegraph services

After a brief initial period of intolerable technological problems and public skepticism, the demand for telegraph services in the United States grew and remained strong until the telephone finally displaced the telegraph during the first half of the twentieth century.[40)] The central position occupied by the telegraph during the structural changes of the U.S. economy in the late nineteenth century is widely acknowledged. The reliance on the telegraph by the increasingly more complex and far-reaching industrial enterprises is documented by Chandler (1977). Field (1992) emphasizes the large capital savings resulting from not double-tracking U.S. railroads and instead relying on controlling trains by telegraph. DuBoff (1983) underlines the influence of the telegraph on perfecting markets and lowering transaction costs, both of which were behind the increasing pace, efficiency, and integration of U.S. capital and commodity markets.

The lack of alternative means of quickly and reliably communicating information across long distances continued until the 1880’s, ensuring a virtual absence of substitution away from telegraph services. On the contrary, the demand of heavy users in sectors like the press and financial services was such that they began leasing entire telegraph lines for exclusive use. It was their demand for fast, economical, and secure transmission of information that led to the practice of leasing telegraph lines for use by one firm or a group of firms in one industry and the quick adoption of advanced telegraph machinery on those leased lines.

Likewise, it was the same kind of demand for faster, cheaper, and more secure telegraphy that led companies to adopt the use of word-level codes. The widespread use of such codes can be seen as user-side innovation aimed at overcoming the inefficiencies of the letter-by-letter manual telegraphy supplied by Western Union on public lines.

C. The role of supply and the network nature of the telegraph

The roles of the institutional framework and demand for telegraph services explain some aspects of the history of the U.S. telegraph industry. However, a fuller understanding requires examining the supply side of the industry, studying the dynamics of telegraph technology adoption in the context of the telegraph as a network industry.

The telegraph clearly qualifies as a "network technology" due to the technical interrelatedness among its components and the benefits of economies of system scale. As is typical of network industries, the

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[39)] Thompson (1947), p. 334

[40)] Reid (1879), pp. 125-26 and DuBoff (1983), Table 1, p. 256

economic value of services offered by the telegraph system was directly related to the extent and interconnectedness of the wire network, and also to the degree of integration and coordination among its constituent links. It was the emergence and quick realization of inefficiencies associated with a disintegrated network comprised of numerous independent telegraph lines which helped steer early industry participants to cooperate and made horizontal integration economically attractive, since the latter allowed internalization of positive network externalities.

To better understand the implications of the network aspect of telegraph technology on industry development, we first need to identify the sources of technical interrelatedness among the main components of a telegraph system: wire network, transmitting equipment (hereinafter, "transmitter"), receiving equipment ("receiver"), human operators, and communication protocol ("code"). Although theoretically there is some degree of interrelatedness between every pair of these components, from an economic perspective, only a few mattered. Those were (1) the relationship of the *quality* of wire network and the *degree of variability* tolerable by the receiver, (2) the transmitter and the receiver, and (3) operators and the mode of transmitting and receiving telegrams.

C-1. Morse telegraph as the lowest common denominator

In the case of Morse telegraphy, however, the technical interrelatedness among the physical components of the telegraph system was largely unimportant. Almost any electrical conduit between two points could be used to transmit telegrams since even significant signal distortion rarely led to errors given the flexibility and error-correcting capabilities of human operators performing the decoding. This decoupling of the wire network from the rest of the telegraph system afforded by employing the Morse system made it the "lowest common denominator" technology of choice when disparate telegraph lines were being unified during industry consolidation. The varying and often poor quality as well as the sheer geographical extent of the American telegraph wire network made the other, more advanced telegraph technologies, although fast and dependable in controlled experiments and on shorter, higher-quality links, impractical for widespread deployment.

Furthermore, the simplicity of the Morse telegraph required only a loose coupling between the Morse transmitters and receivers - any means for opening/closing of the circuit on one end and sounding beeps on the other was sufficient. Finally, the physical aspects of the Morse key and sounder were not fundamental to the Morse coding and decoding functions performed by the operators, rendering insignificant the dependence of operators on particular kinds of keys and sounders. In fact, many different kinds proliferated. The only major source of technical interrelatedness in the Morse system of telegraphy was the link between each operator and the common Morse code.

C-2. Morse code

Almost any one-to-one correspondence between letters of the alphabet and durational symbols could have been used in conjunction with almost any wire network, Morse key, and Morse sounder. However, in order to prevent the emergence of a Tower of Babel across the telegraph network and its predictable inefficiencies, it was critically important for all operators to coordinate on the use of a single code. In addition to the obvious increasing returns to adoption of a single code, there were also significant costs to reversing an adoption decision, since changing the code would have entailed retraining operators, coordinating a switchover, and operating at a below-optimum level until the switchover is complete and operators have regained their highest possible level of proficiency. Studies and interviews with operators revealed that it took at least half a year of training to reach "slowest main line rate" and about two years to become an expert Morse operator.41) These factors explain the almost immediate lock-in to a single code, which came to be called the American Morse Code, and the stalwart unwillingness of U.S. telegraphy to switch to the more streamlined International Morse Code devised in Europe in 1854, only a decade after the first U.S. line, and from then on employed throughout Europe and the wider world.

But was the American Morse Code significantly inferior or superior to the International Morse Code, or to some other feasible code? Although a scientific study of the tradeoffs between the measurably slower International Morse Code and the more error-prone and harder-to-learn American version could not be located, an argument can be made that American Morse Code is not the best possible code that could have been employed. If one were starting anew to design the optimal code for use with the Morse key and sounder, three main factors would have to be considered: (1) linguistic factors, especially the frequency of occurrence of letters in text most commonly transmitted by telegraph and the orthography of the language, (2) human factors, especially the speed of acquisition, speed of manual entry, and error tendencies in both production and reception of the code, and (3) technical factors such as physical characteristics of the key and the sounder. However, in designing his code, Morse only briefly considered linguistic and technical factors and did not make any effort to optimize the code with respect to human factors.42) Hence it is unlikely that he devised the optimal code. In fact, it would have been more efficient to also assign codes to common letter groups such as "tion" and "ing," as was done in the Meyer code used by the military.

During the development of the code in the 1830's, Morse first considered numerically indexing all words in the dictionary and supplying a dot and dash alphabet for digits only for transmitting the word indices. Early experiments, as well as the dilemma of what to do about proper names, convinced him to switch to a dot-and-dash code for the entire alphabet. He obtained counts of letter types from a local print shop and used that as an indicator of the frequency of letters in English text. Morse had no knowledge of the textual composition of the telegrams of the future and the implications on code efficiency. He did not anticipate that receiving by sound as opposed to reading the dots and dashes on paper will become the prevalent way to receive telegram transmissions. He did not think the inconsistencies due to inserting extra spaces in some letters (the so-called "spaced letters") and lengthening dashes of some other letters will increase errors and training time. In retrospect, it is obvious that he could have devised a better code. But the code Morse devised was good enough to be practical, and within a few months of commercial use it became locked-in such that it was no longer within his power to change it. An account written in 1884 by the main technical officer of Western Union, George

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41) Bryan and Harter (1897), p. 29 and p. 49

42) Morse (1912) details his father's invention of the dot and dash alphabet

B. Prescott, summarized the situation:

> The spaced letters were very early found to possess the practical inconvenience of being liable to be confounded with other letters or combinations of letters, unless very carefully rendered, which fact has been known to give rise to serious errors, though this has occurred much less often than would at first be supposed likely....
>
> After the introduction of the alphabet into practical use, and the discovery of the above mentioned defect, Morse endeavored to modify the alphabet in such a manner as to obviate it, but was unable to overcome the prejudices of the operators against a change, even upon the first public line, and, therefore it was reluctantly suffered to continue. Upon the introduction of the Morse system into Germany many years ago, an improved arrangement of the alphabet was devised, and this has since then been adopted in all parts of the world except America. It has been proposed to introduce the European alphabet in this country also, but though the advantages of such a reform would doubtless be numerous, yet it may perhaps be better to suffer some inconvenience from an acknowledged imperfection, than to attempt to remedy it by introducing a change that would for a time cause serious annoyance to the thousands of skilful [sic] *operators* now in service.43)

By recognizing "annoyance" as a euphemism for "short-term switchover costs," the lock-in of the first-mover disadvantage suffered by the U.S. telegraph industry is clear. By opting to rely on Morse’s "lowest common denominator" technology which was uniquely capable of operating across all varieties of wire circuits, the industry evolved in the direction of decreasing technical interrelatedness among the physical components of the telegraph system. However, it instead became reliant on a telegraphic process dominated by human skills, which in turn engendered network externalities of a human capital nature and limited the industry's flexibility to change in a different way.

C-3. The hardware puzzle: persistence of manual Morse telegraphy

Viewing Morse telegraphy as a lowest common denominator helps explain the prevalence of Morse telegraphs until the 1880's. After then, however, the improved wire network and the advanced state of automated telegraph technology no longer necessitated such complete reliance on the manual Morse system. Yet it continued to prevail for at least another three decades. Rather than install automatic telegraphs to drastically reduce labor costs, which accounted for over half of its operating expenses, Western Union merely replaced the pen with the typewriter as the tool for transcribing received telegrams.44) Based on the evidence examined for this study, the reasons for this unlikely persistence of an inferior technology are unclear, especially given that at this late stage in the telegraph industry, much of the network externalities have been internalized by the Western Union monopoly. An interesting further inquiry may be to examine the documents of Western Union Company for evidence that the

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43） Prescott (1885), pp. 430-31

44） U.S. Bureau of the Census (1905), p. 30, Table 39 and Gable (1988), p. 34

monopoly did not adopt superior technology due to its desire to maximize short-term rents on its proprietary telegraph network prior to being upstaged by the telephone. The threat to the telegraph was certainly felt in that time period: explosive growth of the telephone network began in 1879 and by 1902 telephone wire mileage exceeded that of the telegraph by nearly a factor of four.45)

C-4. The software puzzle: Coding inflexibility

Not only was the U.S. telegraph industry mysteriously stuck unnecessarily relying on the inferior Morse technology well beyond the 1880's, at the same time it also exhibited a puzzling lack of flexibility in adjusting its "software" telegraph coding practices to grow by better serving sector demands. Western Union chose to meet the growing demand for telegraphy services by certain sectors such as financial services and the press in a relatively "hands-off" fashion. It leased out "private lines" to some businesses and connected others to regular main lines via direct cable drops. It went no further in trying to tailor its services to the special needs of the different classes of large users, thereby remaining a strictly horizontal business focused on transmitting sequences of alphanumeric characters regardless of their origin, destination, or semantic content. The inefficiencies due to the retention of manual Morse telegraphy were further aggravated by refusal on the part of the telegraph industry to adopt the use of word-level coding to optimize for predictable linguistic regularities.

As a result, it devolved to the sector users to develop and adopt word-level codes specifically tuned to their lexicons and the telegraph tariff structure as a means for optimizing telegraphy costs externally to the inflexible Western Union "black box." From the early telegraph days, telegraph companies countered increases in coded messages submitted by customers and the resulting strains on the ability of manual Morse telegraphy to retain speed and accuracy, by charging a premium for transmitting coded words.46) Western Union adhered to this practice and in 1908 moved to replace the confusing requirement of pronounceability of all words claimed to be uncoded with a more restrictive method of deeming words to be uncoded.47)

The failure to adopt word-level coding practices was shared by other telegraph services around the world. Having ignored proposals of sensible standards for word-level coding at the Conference of London in 1903, much of the effort at that and subsequent international telegraph conferences was devoted to working out effective means for regulating the submission and pricing of customer-coded telegrams.48) Although it is likely that the politics of largely government-controlled European telegraph services were behind this at the international level of cooperation, it remains unclear why Western Union and Postal Telegraph Company showed a similar lack of flexibility given that they were independent of the European regulations in their U.S. operations.

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45) U.S. Bureau of the Census (1905), p. 7, Table 1

46) Reid (1879), p. 429 lists "The increase of rates on messages written in cypher" as one of the agenda items discussed at the first American Telegraph Convention in 1853.

47) Friedman (1928), p. 71

48) Friedman (1928), p. 28

Ⅵ. Comparison to other network industries

Much of the dynamics of telegraph technology adoption and industry evolution related above has direct analogues in other network industries. In particular, the three network industries most studied from the perspective of economics of standardization, namely railroads, electricity supply, and typewriters, all went through an initial phase of competing standards and eventually emerged dominated by a single standard. The predominantly human capital-based source of technical interrelatedness in the nineteenth-century telegraph network, however, stands in sharp contrast to those in railroads and electricity supply. In the latter two industries, technical interrelatedness was exclusively a feature of physical capital comprising different components of the respective technologies. In the case of railroads, the spacing between rails had to match the spacing between wheels of cars and locomotives.49) In the case of electricity, the electrical equipment connected to the electricity network had to match the utility companies' generating and distributing equipment in terms of voltage and frequency.50)

The typewriter industry offers an example of technical interrelatedness which lies between the physical capital extreme evidenced by railroads and electricity supply and the human capital extreme of the telegraph industry. The operative technical interrelatedness in the typewriter industry was the coupling of the human capital represented by the pool of typists trained to use a specific keyboard layout and the physical capital embodied in the typewriters.51) The source of inertia preventing changing the layout was the cost of retraining typists or reconfiguring typewriters. Although there is a degree of similarity between the telegraph and typewriter industries stemming from the human capital element behind network externalities in both industries, the telegraph is nevertheless more akin to railroads and electricity in the sense that the presence of a physical, production-side network drove the industry first to cooperation and eventually to an extreme degree of horizontal consolidation.

Another distinction between the telegraph industry on the one hand and the electricity and railroad industries on the other is the lack of telegraph "gateways." A gateway is a device which permits distinct production systems to be used in conjunction with each other and within a larger integrated network.52) In electricity supply industry of the 1890's, the rotary converter was a gateway enabling relatively cheap interconnection of the two competing technologies: alternating current (AC) transmission lines and direct current (DC) distribution networks.53) In the railroad industry, a variety of gateways were employed to cope with varying gauges, including movable wheels/axles and three-rail tracks.54) The importance of gateways lies in their ability to tip the standardization process toward the technology which offers the lowest costs at the time of gateway introduction, as was the case in the electricity supply industry.55) In the case of the telegraph, the lack of technology to translate telegraphic codes or otherwise

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49) Puffert (1991)
50) David and Bunn (1988)
51) David (1985), p.334
52) David and Bunn (1988), p. 170
53) David and Bunn (1988), p. 181
54) Puffert (1991), p. 76
55) David and Bunn (1988), p.198

enable different telegraph systems to communicate limited gateway techniques to manually receiving a message on one type of telegraph system and retransmitting it on another. Although such activity did take place early on in the industry, the associated costs (and increase in errors) were prohibitive since labor input per telegram had to be doubled. Thus, network integration in the telegraph industry, unlike railroads and electricity supply, was effectively an all-or-none concept, since no reasonable gateway techniques or devices existed.

Ⅶ. Conclusion

Several promising avenues of investigation remain to be explored in search for a better understanding of the dynamics of telegraph industry evolution. One approach is to compare the patterns of development in the U.S. telegraph industry with those of European nations. The differences between nineteenth century European telegraphy and its American counterpart run much deeper than the differences in Morse codes. European telegraph companies also differed by requiring much higher general qualifications of the operators they hired, building and maintaining a wire network of much higher cost and quality, and operating a much greater mix of telegraph technologies including printing and automatic telegraphs.56) Another perspective on the development of the industry could be gained by studying industry data, both at the aggregate and firm level, to quantify the effects of technological standardization and industry consolidation. A third possibility is to make inter-industry comparisons identifying parallels and distinctions between the capital-labor tradeoffs made by the telegraph industry and those exhibited by other nineteenth century network industries.

The history of the American telegraph industry provides an interesting case study of technology adoption in the presence of network externalities and in the absence of institutions for standard-setting. Features identified by the theoretical framework for technology adoption have reasonable historical representation in the case of the evolution of U.S. telegraphy. Unlike the other network technologies which have been studied from a similar perspective, the telegraph industry was able to evolve away from strong technical interrelatedness involving physical components of the network, but was instead affected by the less tangible network externalities stemming from the human capital accumulated by telegraph operators. Additional research is needed to understand the reasons for the persistence of the inferior Morse telegraphy and coding inefficiencies long after network externalities have been internalized by a monopoly.

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56) Shaffner (1867), p. 761-3 and Prescott (1860), p. 231

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