Ingenious Yankees: The Rise of the American System of Manufactures in the Private Sector

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A bald definition of the word "History" would be -- "a narrative of events," -- "an account of that which is known to have occurred". But as ordinarily used, the word is understood to include more than a simple statement of facts, in that there is an attempt to discern contemporary as well as previous conditions, as affecting the events which are narrated. For the real aim of History should be, not simply to gratify curiosity, but to inform the reader of actions, occurrences or events which have taken place, in connection with, or in consequence of, certain conditions, and thereby to serve as a means of instruction, as well as of information to the reader.

Edward A. Marsh, Master Mechanic,
Waltham Watch Company

This is a study of the interaction between technology and the market place and the mechanism through which that interaction occurred in the nineteenth century. It concerns the economic and cultural/technological matrix through which mechanics and entrepreneurs created the private sector of the American System of Manufacturers. The American System of Manufacturers is gener-

BUSINESS AND ECONOMIC HISTORY, Second Series, Volume Fourteen, 1985.

Library of Congress Catalog No. 85-072859.

ally characterized by the mass production of interchangeable parts on specialized machinery arranged in sequential operation.

The examination of four nineteenth century industries -- wooden movement clocks, axes, watches, and typewriters -- traces the development of the American System without government subsidy in any form, either in capital, in transfer of technology, large orders for goods, or tax incentives. The data, many of which are derived from new and somewhat unusual sources, are especially interesting since they illuminate such important interpretive areas of American economic and technological history as the economic reasoning of nineteenth century entrepreneurs, economic and technical forces behind new product design, the interchangeability debate, new materials, the economics of mass production, the existence of a "technological imperative," and market response. Finally, these case studies complete the study of the classic American System industries first enumerated by Joseph W. Roe in 1916.

Nineteenth century mechanics played the single most important role in the rise of the American System. As individuals, they invented the new machinery of mass production and designed (or redesigned) the products to be mass produced. Eli Terry developed techniques to produce large quantities of clocks; then, reacting to an assembly problem, he redesigned the clock itself to solve that problem. David Hinman and Elisha K. Root invented axe manufacturing machinery and changed the process and the product dramatically. Aaron L. Dennison and a host of brilliant mechanics who followed him at the Waltham Watch Company invented the most sophisticated automatic machine tools in the nineteenth century, introduced the metric system to American manufacturing, developed a new gauging system, and designed new watches in order to achieve mass production. William K. Jenne and Jefferson Clough redesigned the Sholes & Glidden typewriter and eventually designed and built the Remington typewriter factory that mass produced the writing machine. In each case history, the individual mechanics and engineers stand out as the agents of technological change. They were the individuals having the bright ideas about product design and machine design. They were not alone in their work, but functioned in a particular environment, the environment of the nineteenth century economy and the nineteenth century businessman who viewed his economic world in his own particular way.

This work advances the historical view of the rise of the American System in two ways. First, it provides private sector data to balance the excellent studies of the public sector (that is, the arms industry). Second, this study provides the data to synthesize the two opposing historical schools of thought on the rise of the American System, the economic and the noneconomic. This synthesis leads to a model explaining the nature of technological change in the American economy.

When considering the development of technology in the nineteenth century in general vis-a-vis the private sectors, the private sector held the technological lead from 1807 to the mid 1820s. Between the mid 1820s and the late 1840s, the federal armories shared the forefront of technological change with the private sector. In the 1850s, however, the federal armories stagnated after achieving an acceptable degree of mass production and interchangeability. By the 1860s and the 1870s, innovation in the private sector had again moved past the public sector, especially in industries like watch and typewriter manufacturing that pioneered new techniques such as precision press work, precision automatic machining, precision gauging, and vulcanizing. By the early twentieth century, the private sector had left the public sector far behind.

These shifts in American technological leadership over the nineteenth century centered on the incentive to innovate. In the closed environment of the federal armories, technology stagnated as change occurred in design but not in manufacturing methods. In the private sector, enthusiastic mechanics found expression for their ideas through economic incentives.

The four case studies, which span the entire nineteenth and early twentieth centuries from 1807 to 1924, deal with a different product and provide insights into the rise of the American

System. Eli Terry's inventions illustrate how advances in production technology led to design innovation in wooden movement clocks. Together, the new production technology and product design drastically reduced the cost of clocks, creating new demand and greatly expanding the market. The development of axe manufacturing technology at Collins & Co. took place in an already strong market. Collins learned to mass produce axes (1832-1849), cut costs dramatically with highly efficient machinery that allowed him to compete very effectively in a crowded market. The successful manufacture of watches at Waltham (1849+) was an entirely new industry, and its mechanics and entrepreneurs faced the problem of developing a new and very precise technology. They responded by inventing and building the most sophisticated automatic machinery in the nineteenth century. The typewriter industry faced the problem of producing the most complex consumer durable good manufactured in the nineteenth and early twentieth centuries. These manufacturers developed new production technologies and assembly techniques, notably "exercising" machines and fully adjustable typewriter designs.

One of the most exciting discoveries of this study is the economic importance of product design. Wooden movement clock design was an integral part of the manufacturing technique. Eli Terry first produced clocks that were difficult to assemble. In 1816, his new clock featured an adjustable escapement, which lowered its price through cheaper manufacturing. This invention remained a standard feature of American clocks for over a century. In the watch industry, American designers discarded the complicated power transmission system of the English watch and substituted a simpler design, the "going barrel," eliminating hundreds of parts and a difficult manufacturing process. In sum, American mechanics designed their products to reduce manufacturing costs by easing assembly through adjustment during assembly and increasing tolerances during fabrication.

There is a second aspect of product design in the private sector. Product design not only made things cheaper and often better, but also provided a range of goods across a broad economic spectrum. In 1890, typewriters ranged from the very expensive to the very cheap, from the Remington No. 6 ($125.00) to the Champion ($15.00). Waltham watches ranged from $75.00 to $3.00. The spectrum of products included a broad range of price, quality, reliability, speed, flexibility, and so on, based primarily on design. The same phenomenon was found in the cycle industry, the clock industry, the sewing machine industry, and the automobile industry. Henry Ford may be properly noted for having developed the assembly line, but in a different light, he was simply another in a long line of entrepreneurs producing cheap goods, including Waterbury watches, Champion typewriters, and Iver Johnson firearms.

Historians -- perhaps more than the nineteenth century capitalists and engineers they study -- are concerned with interchangeability. In the federal armories, interchangeability was a technical ideal to be pursued. In the private sector, historians now believe, interchangeability was merely an advertising device, never achieved in practice. This is a startling conclusion, given the attention paid by nineteenth century observers. The four case studies in this paper (and my dissertation) provide a new definition of interchangeability and interpretation of the debate. Before entering that debate, historians need an accurate and feasible definition of interchangeability.

Historians have defined interchangeability as some absolute degree of sameness that allows the worker assembling a product to select the parts at random and put them together without any fitting. However nineteenth century manufacturers never thought of interchangeability as an absolute, and interchangeability meant different things to different manufacturers. This spectrum of concern was a function of the product itself. At one end, for example, Collins & Co. did not attempt to manufacture interchangeable axes but concerned itself only with the general shape. Axe manufacturers were simply unconcerned about small variations in size and shape.

Further along the spectrum, wooden movement clock manufacturers were concerned with interchangeability and did make interchangeable parts. But they only made their parts as interchangeable as necessary. They designed their clocks to be easily adjustable in the assembly process to compensate for this rough degree of interchangeability.

Near the opposite end of the spectrum, at the Waltham Watch Company, interchangeability reached its nineteenth century zenith in parts produced on automatic machinery. But it still fell short of some absolute criterion. Despite virtually total interchangeability of screws, wheels, pivot sizes, and depthing -- all produced on automatic and semi-automatic machinery -- there still remained much hand work in assembling and adjusting, despite the fact that such parts as hairsprings and balance wheels were produced with such machinery. Higher grade watches all required special attention: notably adjustment to both temperature and position was important. The most interchangeable product of the American System was not completely and absolutely interchangeable.

Typewriter manufacturers faced the most severe production problems with the most complex product manufactured on the "interchangeable system." The typewriter required many aligners, assemblers, and adjusters to finish its assembly. Many manufacturers struggled to solve the problem of "perfect alignment" by designing adjustability into their machines and relying on skilled labor to do the adjusting and aligning. As late as 1953, alignment and final adjustment were critically important aspects of typewriter manufacturing at the Royal Typewriter Company, often requiring two to three hours per machine in the final stage alone. Thus, each manufacturer faced a different criterion of interchangeability based on the product he was manufacturing.

Interchangeable manufacture was itself only the first step, and interchangeability in and of itself was of no great concern to a manufacturer. It was the assembly and adjustment stage that concerned him most. Hence, there were different degrees of interchangeability, depending on the assembly and adjustment needs of a particular manufacturer and his product. Even perfect interchangeability could still require adjusting and assembly. Consider the assembly of bicycle wheels and spokes. Cycle assemblers had fully interchangeable spokes -- the threads on the ends were the same, they could be chosen at random for assembly -- yet the wheel still required the careful adjustment of the spokes in order to run true. If the wheel was improperly trued, the cycle was virtually unridable. Assembly and adjustment of cycle wheels simply had to do with the nature of the product.

The principal is the same for other products as well, including watches and typewriters. In the manufacture of watches and typewriters, entrepreneurs and mechanics confronted the same kinds of assembly and adjustment problems as the cycle manufacturers, problems differing only in the requirements of their different products. The more complicated the mechanism (watches and typewriters), the more adjusting was necessary in the final stages of production. The number of parts were vastly larger in typewriters and watches than in wooden movement clocks; thus they required more adjusting simply because more parts had to fit together. The kinds of adjustments necessary differed as a function of the product. Watch manufacturers matched escapements, poised balances, and adjusted timing screws. Typewriter manufacturers aligned type and adjusted the tension, shift, and so on. Manufacturers found it impossible to manufacture perfectly interchangeable parts for increasingly complex products. Logically, if all parts were the same, there would be no fitting or assembling or adjusting. But in practice there was (and still is). Manufacturing -- even given a high degree of interchangeability -- necessarily required the adjustment of fine mechanisms.

Nineteenth century engineers understood the concept of manufacturing interchangeable parts that were not perfectly interchangeable as well as the need to adjust mechanisms. W. F. Durfee wrote concerning "the Art of Interchangeable Construction in Mechanisms," that "super-refinement of accuracy of outline and general proportions is not always necessary or even desirable. There is a recognized roughness of interchangeability."

This "roughness of interchangeability" found expression everywhere in the American economy, including the production of many cheap and simple goods. Simpler design and fewer working parts meant fewer gauges and manufacturing steps. Thus it was easier to hold to fewer (and less strict) tolerances. Many of the materials used in the cheaper goods also made manufacturing easier. Compare the paper dials of Waterbury watches to the enamel dials of Waltham watches. Again, the nature of the product was critical. Conversely, interchangeability is relatively difficult to achieve in high quality, expensive, precision goods such as railroad watches and typebar typewriters. These goods had many more parts, which implied more manufacturing steps and, hence, more gauging and checking. With more parts fitting together, there were far more opportunities for problems in assembly. The statistical probability of needing adjustment is simply far greater in more complex mechanisms, a kind of technological imperative.

The private sector manufacturers of the American System products faced a very real "technological imperative." This is especially true in the sense that when a manufacturer decided to make a product of a particular quality, he was forced to employ given techniques and certain general designs -- he had no alternatives. This is not to imply that manufacturers did not develop new technology and new designs, but many adopted and adapted existing technology. The mix of existing and new technology was determined by the mechanics in charge of production, the agents of technological change.

Nineteenth century mechanics worked closely and harmoniously with nineteenth century entrepreneurs to develop the new technology and implement their new designs. Eli Terry was both inventor and entrepreneur, but he relied heavily on local merchants to provide the capital and sell the output of his embryonic factory. Several mechanics are known to have worked with him. David Hinman and, especially, Elisha K. Root worked quite closely with Samuel W. Collins to develop axe manufacturing technology. Aaron L. Dennison worked closely with Edward Howard in the early years of his watch manufacturing enterprise. William K. Jenne and Jefferson Clough worked with the Remingtons for years in apparent harmony.

Nineteenth century mechanics were fully aware of the three-fold economic implications of the technological changes they brought about: the economics of mass production; the economic reasoning of the entrepreneurs with whom and for whom they worked; and the need to respond to the market. These mechanics understood the economics of machine production. They realized that the use of specialized machinery could sharply improve productivity and, hence, lower costs. They knew that spreading manufacturing costs over a large number of units lowered unit costs. They understood that a properly designed product could speed assembly, thus saving time and cutting costs. They understood the structure of nineteenth century demand, especially the demand for lower-priced goods. Unlike twentieth century economists who see technology as simply another "factor of production," the mechanics and entrepreneurs of the nineteenth century comprehended technology as the *most important* factor of production.

Technology changes the proportionate use of all other factors of production. It is more than simply another economic factor of production; it is the critical factor of production because it shapes the use of labor, the use of raw materials, and the use and rate of return on capital. As the case studies demonstrate, entrepreneurs did not explicitly consider the cost of labor or the cost of capital or the cost of raw materials in deciding to innovate. They considered the technical production needs of their products, as well as the need to produce larger quantities, and then responded to the productivity of their machinery. At Collins & Co. for example, David Hinman's first die-forging machine increased the productivity for a single skilled striker (with an assistant) from 12 to 300 axe heads per day. The cost of labor and capital were virtually inconsequential in the face of such an improvement in output. The labor cost per axe poll dropped so dramatically that Collins had primarily to worry about finding the capital, not what the machine cost.

The psychological impact that such returns on investment (returns typical of the first stages of technological innovation in manufacturing) had on the outlook of the typical nineteenth century entrepreneur was substantial. Confronted with the reality of sharply falling costs, entrepreneurs were surely willing to invest in such an increase in productivity and the mechanics who promoted such machinery.

Both economic and technological historians have missed the most important aspect of technological change and economic development in the nineteenth century, the relationship between the mechanic and the entrepreneur. Economic historians seem to have been too preoccupied with finding a general theory of economic development and technological change, while historians of technology have simply ignored economics and economic historians altogether. Both groups have tended to ignore the businessman whose needs are quite practical and immediate -- how to produce a better product more cheaply and how to expand the market and meet the competition. Only by focusing on the entrepreneur and the mechanic working together can historians begin to understand how and why technological change took place in general and how the American System in particular became a dominant feature of the American economy.

The interaction between the mechanic and the entrepreneur is the critical relationship in nineteenth century technological change and, hence, in economic growth. It is the mechanism through which changes in technology found expression in practical applications and transformed the light manufacturing sector of the American economy from a craft tradition to a series of major industries. The mechanic and entrepreneur generally knew each other well, often having a close personal relationship as well as a business (employer/employee) relationship.

Perhaps the most pervasive, economy-wide impact of the private sector American System was the entrepreneur's incredible flexibility and his response to changes in the market. In virtually all of the private sector American System industries, there was a pattern of competition along the following lines. First, inventors and entrepreneurs struggled to develop and manufacture a new product or an American variation of an existing product, usually as a fairly high-grade item. Subsequently, the market was flooded with competitors, both at the same quality level and at a lower, or cheaper, quality. A period of savage competition ensued during which most firms and products disappeared from the market. Finally, the enduring firms emerged, each with its share of a particular market.

This pattern emerges in clockmaking, watchmaking, and typewriter manufacturing. In the watch industry, for example, the Waltham Watch Company pioneered the manufacturing of watches. Shortly after its success was insured, about 1864, a host of competitors entered the market, hiring away Waltham mechanics and operatives to build and run the new factories. The watches of these first competitors were strikingly similar to the Waltham Model 1857. Within a few years, by the early 1880s, competition appeared in the form of cheap (later known as "Dollar") watches. By the 1890s, the Waterbury Watch Company had created and secured a market in cheap watches that Waltham was unable or unwilling to enter. The same phenomenon occurred in the typewriter industry and the clock industry as well. The promise of mass production through the new technology of the American System made these significant changes in the market possible. Without these new techniques, there could not have been and would not have been such a swift market response by private sector entrepreneurs and such a wide variety of quality.

One aspect of the rapid response and the wide range of quality was the introduction of new materials in the private sector industries. In the private sector, there were no technical constraints on either the materials used or their quality as there were in the federal armories. Manufacturers used wire, wood in many forms, paper, enamel, paint, nickel plating, fine steel springs, gold, silver, cast iron, and plastic (celluloid). There was not only a much greater need to innovate in the private sector, but also a much greater freedom to do so. These manufacturers were unrestricted in product design and material use in developing new products.

Finally, this study synthesizes two schools of thought on the rise of the American System and the nature of technological change: the economic and the noneconomic. Economists and economic historians have offered theoretical arguments to explain the rise of the American System, but none has studied the technology itself. H. J. Habakkuk, whose work started the debate and whose concept of "labor scarcity" still dominates the literature, cast his arguments on two theoretical grounds. First, the relatively scarce supply of labor in America compared to Britain was important. Second, the interest rate influenced the rate of technological change. Most economists and economic historians consider technology as no more than another input, such as labor or raw material or capital, simply responding to economic pressure. Historians of technology have objected to this approach but have never rejected the argument on theoretical grounds.

Technological historians have also developed a curiously blind perspective on technological change, a view focused on the intellectual character of the engineer termed "technological enthusiasm." The theory of technological enthusiasm explains technological change as the result of engineers promoting new ideas with no economic basis.

The concept of "technological enthusiasm" is not inconsistent with the economic forces at work. Indeed, they are fully compatible. Engineers and mechanics were not blind to the economic needs of their firms and often had strong economic evidence on which to base further work. The economic rewards for technological innovation in manufacturing were both substantial and quite obvious. The price of Eli Terry's wooden movement clocks fell quite fast as the new technology spread. At Collins & Co., Elisha K. Root and Samuel W. Collins saw worker productivity skyrocket with the introduction of David Hinman's axe forging machine in 1832. After the Civil War, Royal Robbins, the treasurer and major stock holder of the Waltham Watch Company, repeatedly justified the company's investment in automatic machinery by insisting that they reduced watch prices. Simultaneously, the mechanics at Waltham reveled in the technology they developed in response to noneconomic forces as well as the economic pressure of competition. Clearly, the mechanics and entrepreneurs of the nineteenth century understood the concept of spreading their unit costs over a large volume by producing more units with machinery.

None of these economic incentives is inconsistent with the theory of technological enthusiasm. Indeed, the economic rewards (or the possibility of such rewards) for innovation could be interpreted as the mechanism through which the mechanics could give free reign to their imaginations. Their enthusiasm for invention and design found an outlet in the market place, but the market place provided only a part of the incentive, the other part being the engineer's excitement and enthusiasm for his project. Neither the market alone nor the engineer's enthusiasm is enough to bring technological change to fruition, both are required in some undefinable proportion. Without the market, the engineer's new idea remains just another new idea. Through the market, it becomes reality. However the market alone is unable to create new ideas. The mere existence of an economic demand does not imply that a successful product will appear to meet it. The two forces (the economic and the noneconomic) must coincide, must work simultaneously, in order to result in a technically and economically successful product or process.

The study of the interrelationships between mechanics and entrepreneurs illustrates that both the economic and noneconomic approaches to technological change are incomplete. In the absence of an economic system through which to express themselves, these nineteenth century mechanics would have failed to transform their ideas into reality. Yet the economic system by itself was (and still is) incapable of producing new technology. It was through the combination of a viable economic system capable of transforming the engineering ideas produced by enthusiastic mechanics into reality that the American economy in general and the American system of Manufacturers in particular grew and flourished in the nineteenth and early twentieth centuries.