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CHAPTER 2

INTERCHANGEABLE PARTS AND MASS PRODUCTION

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In 1800 the manufacturing sector accounted for less than ten percent of U. S. commodity production. By the end of the century it accounted for over fifty percent. A unifying theme of this dramatic growth in the manufacturing sector was what came to be referred to as "The American System of Manufacturing" (Hounshell 1984: 331-336).[1] Economic historians have traditionally characterized the American system as the assembly of complex products from interchangeable individual parts (Rosenberg 1972: 87-116). The System was developed for the manufacture of guns for the Army at the national armories at

[1] I am indebted to Nathan Rosenberg and Merritt Roe Smith for comment on an earlier draft of this chapter.

Springfield, Massachusetts, and Harpers Ferry, Virginia (Smith 1977).[2]

My primary purpose in this chapter is to discuss an early example of the role of military procurement in the development of general purpose technology in the United States. The American, or more appropriately, the New England, Armory System introduced during the first half of the nineteenth century had a pervasive impact on the development of American manufacturing. It was the precursor of what has been termed the "Fordist" system of mass production. A second theme of this chapter is the difficulty of achieving rapid technology transfer even when the participants are working under a unified command and control system or are in the same industry.

[2] The conceptual basis for a system of uniform ordinance manufacture based on interchangeable parts was initially developed in France. It was first applied to the manufacture of gun carriages... The concept was diffused to the United States by French officers during the Revolutionary War. A continuing puzzle is why a machine process for production of guns was first developed in the U.S. rather than France remains unresolved (Smith 1985: 39-86). Ames and Rosenberg (1967) suggest an induced technical change interpretation of the prior adoption of machine methods for producing muskets in the U.S. than in Britain).

INTERCHANGEABLE PARTS[3]

The significance of interchangeability can best be understood when compared to the handicraft technology previously used in gun making. Handicraft gun making involves precisely fitting together, primarily by hand filing, individual components produced by a large number of craftsmen. Substantial skill and patience were required for tasks such as filing and recessing the gunstock to properly accommodate the lock and barrel and correctly arranging the pin and screws. In contrast the system of interchangeability required less skill, and thus vastly simplified gun production, repair and maintenance. It also meant that an army in the field no longer had to be accompanied by armorers to repair a broken part or fit a new part (Mokyr 1990: 136, 137).

[3] In this section I draw substantially on Smith (1977) and Ruttan (2001:426-428).

Springfield and Harpers Ferry

Prior to 1797 the War Department purchased it arms, whether imported or produced domestically, from private contractors. In 1794 President Washington, disturbed by the inadequate performance and corruption of the contract system, proposed and the Congress passed a bill to create up to four public arsenals and magazines to manufacture and supply arms to the Army Department. The bill authorized the president to decide on the locations and to select (and dismiss) the armory superintendents. A site at Springfield, Massachusetts, already owned by the government, was selected shortly after the bill was passed. It was not until 1798, after considerable controversy, that a second site at Harpers Ferry was selected (Smith 1977: 28-32).

In 1812 an Ordnance Department was established as an agency for the inspection and distribution of military supplies. Responsibility for the Springfield and Harpers Ferry Armories were placed under the jurisdiction of the Department. Its first

Director, Colonial Decius Wadsworth staffed the Department with able young military engineers. His chief assistant and successor, Colonel George Bomford, was given responsibility for overseeing and promoting greater efficiency in arms manufacture at the Springfield and Harpers Ferry Armories (Smith 1977: 106). In the decade after the War of 1812 additional armories were established. Several of the arsenals, such as the Springfield Arsenal and the Frankford Arsenal located outside of Philadelphia, played an important role in the industrial development of the regions in which they were located.

Traditionally the manufacture of rifles and pistols involved several separate specialized branches of labor: barrel making, lock forging, lock filing, brazing, stocking, finishing and assembly. "Despite the rudimentary division of labor involved in the manufacturing process each gun remained a handicraft product," (Smith 1977: 79). When Roswell Lee was appointed superintendent at Springfield in 1815 he initiated a series of technical and managerial innovations designed to make the

Springfield Armory one of the most advanced manufacturing establishments in the United States. At the time he assumed the position of superintendent the occupational specialties had risen from five to thirty-four. They rose to sixty-eight in 1820, and to over 100 in 1825. The division of labor at the Harpers Ferry Armory lagged behind that at Springfield, reaching sixty-four occupational specializations in 1825. Except for brief intervals a combination of inept, and sometimes corrupt, management and resistance to division labor by the skilled armorers delayed the transition to more complete mechanization of operations at Harpers Ferry (Smith 1977: 79-83; 359-304). [4]

One of the most remarkable pieces of equipment introduced at the Springfield Armory was a lathe for producing gunstocks, invented by Thomas Blanchard. The invention involved the difficult task of solving the problem of how to design a machine that could turn out irregular forms. Superintendent Lee arranged

[4] "While the arms manufactured at Harpers Ferry compared favorably in quality to those made by private contractors, the weapons produced at Springfield were generally preferred by military authorities. It was generally acknowledged that the Potomac armory excelled at making highly finished pattern and presentation pieces, but could not equal Springfield's record for consistently producing a sound, reliable and—after 1815--a more uniform product," (Smith 1977: 101).

for Blanchard to become an “inside contractor.” The terms of the contract called for the Armory to furnish “shop space, water privileges, raw materials, and general use of tools and machinery of the armory. Blanchard agreed to provide his patented machinery royalty free and to hire his own workmen,” (Smith 1977: 135). He was paid thirty-five cents each for the musket stock he produced. The lathe and other machines that Blanchard invented eliminated the need for skilled labor in one of the major divisions of gun production.

As early as 1911 John H. Hall, then a proprietor of a woodworking establishment in Portland, Maine, had developed a prototype of a breech-loading rifle. His initial attempts to patent the gun were not resolved until he agreed to share patent rights with the Commissioner of patents who himself attempted to claim prior invention. Through the intervention of influential political friends from Maine and the Navy Hall was able to bring his invention, now substantially improved, to the attention of the War Department Between 1813 and 1819 he received several small orders for his breech loaded rifles. A test by the Artillery School concluded that Hall's guns were "superior to every other kind of small arm now in use." And "the rifles parts could be mutually exchanged with another thus greatly simplifying the task of making field repairs" (Smith 1973: 201-102). A second military commission found that the machinery developed by Hall to produce his gun was "unparalleled in contemporary practice" (Smith 1973: 206).

In 1819 Secretary of War John C. Calhoun arranged to have Hall appointed Assistant Armorer with responsibilities to undertake the manufacturer of breech-loading rifles at Harpers Ferry. He was to be paid $60 a month and a royalty for use of his machines of $1.00 for each rifle produced. In 1820 he was placed in charge of a separate Rifle Works at the Harpers Ferry Armory which enabled him to pursue his machinery development and rifle production with less interference by the Armory management.[5]

[5] Hall not only developed many of the machines used in the Rifle Works but also the tools with which they were made. Because up to half of the workmen at the Rifle Shop were involved in development the cost of rifles produced by Hall at Harpers Ferry were slightly higher than at Springfield. Colonel George Bedford,

In spite of the greater sophistication of the production system at the Springfield Armory guns with functionally interdependent parts were first produced in substantial quantity by Hall at Harpers Ferry. On December 30, 1822, Hall, writing from Harpers Ferry, informed Secretary Calhoun: "I have succeeded in establishing a method of fabricating arms exactly alike & with economy, by the hands of common workmen & in such a manner as to insure perfect observance of any established model" (quoted by Smith 1973: 1999).

Hall expected that he would have responsibility for producing rifles for both the federal military and the state militias. However a legal technicality inserted in appropriation legislation by the Congress required that arms for the state militias be produced by private contractors. Confronted with this problem the War Department arranged for Hall to make his technology available to Simon North, an innovative arms maker of

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Chief of Ordinance (1821-1842) in the War Department, a strong supporter of Hall-s work, was forced to continuously defend Halls work to the management of the Armory, within the War Department, and to the Congress. Bedford considered the Rifle Works an experimental venture but felt compelled to justify the high costs of the rifles produced at Harpers Ferry to the Congress on the basis of the potential savings that would accrue from the adoption of fully mechanized techniques (Smith 1973: 220-228).

Middletown, Connecticut. After some hesitation Hall agreed to provide the necessary technical assistance and North received a contract with the Ordinance Department in 1828.

By 1834 North was able to produce rifle components that could be exchanged with rifles made at Harpers Ferry. "For the first time fully interchangeable weapons were being made at two widely separated arms factories" (Smith 1973: 212). The system of gun production developed by Hall also influenced arms making practice at the Springfield Armory. It diffused rapidly to other Connecticut Valley arms manufacturers and elsewhere as employees of the Harper Ferry and Springfield Armories transferred their employment and skills to other gun manufacturers (Smith 1971: 241-250).[6]

The role of Eli Whitney in the development of interchangeable parts has been the source of considerable

[6] Hall was forced to restrict his active management of the Rifle Works beginning in 1837 because of a chronic illness (probably tuberculosis). He died on February 26, 1841 at the age of 60. His wife was particularly bitter about what she considered the unfair treatment of he husband by the War Department and the management of the Harpers Ferry Armory. After his death she wrote to Colonel George Talbot at the Ordinance Department: "No one but myself can imagine his days of toil and nights of anxiety while inventing and perfecting his machinery. Had he in 1820 listened to the proposals of foreign governments, he might now be enjoying health and prosperity, yet he refused all because he thought by doing so he should benefit his own government," (cited in Smith 1971: 218).

confusion among economic historians. In his classic work, *A History of Mechanical Inventions,* Abbott Payson Usher credits Whitney's Connecticut factory with assembling muskets from interchangeable parts shortly after 1800 (Usher 1954: 378-380). Subsequent research indicates that Whitney did enter into an agreement with the War Department in 1798 to produce 10,000 muskets by September 30, 1800. Whitney was, however, so heavily involved in litigation over the patent rights on his cotton ginning machine that he neglected to give adequate attention to his gun manufacturing enterprise. The final batch of muskets produced under the contract were not delivered until January 30, 1809. At that time the Whitney's factory did not yet have the capacity to produce interchangeable parts for the rifles that he manufactured (Woodbury 1958; Battison 1966).

In the early and mid-1850's a number of industrial commissions from Great Britain and other European countries traveled to the United States to report on the machine processes used in American manufacturing and to purchase tools and equipment. During a visit to the Army Springfield Armory one such committees selected 10 muskets, each made in a different year between 1844 and 1853, "which they caused to b taken to pieces in their presence, and the parts placed in a row of boxes, mixed up together. They then requested the workman, whose duty it is to "assemble" the arms to put them together, which he did—the committee handing him the parts taken at hazard—with the use of a turnscrew only, and as quickly as though they had been English muskets, whose parts had been kept separated" (Rosenberg 1972: 91).

Diffusion of the Armory System

As transportation and communication improved and as cheap coal became widely available during the second half of the nineteenth century "armory practice" slowly diffused to other branches of manufacturing, usually by the movement of skilled machinists from the New England arms factories to other industries and regions. Assembly of standardized parts became common not only in firearms, but also of locks, watches, clocks, sewing machines and in other wood and metal working industries (Hake 1990; Smith 1991).

The sewing machine industry was the first to adopt armory practice. At the Wheeler and Wilson Manufacturing Company (Bridgeport, Connecticut) the armory system was adapted by formers employees of the Springfield and Colt armories to the production of sewing machines. The Singer Manufacturing did not make the transition to full armory practice until 1873 when it opened a new factory at Elizabethport, New Jersey.

The evolution of the American system was closely associated with the emergence of the machine tool industry (Rosenberg 1963). In 1820 there was no separate identifiable machinery-producing sector. Machinery producing establishments made their first appearance as adjuncts to factories specializing in the production of final products, especially textiles and firearms. As the capacity of such shops expanded they began to sell machines, first to other firms in their own industry and then to firms in other industries. With the continued growth in demand for an increasing array of specialized machines, machine too tool production emerged by the early 1850's as a separate industry. It played a critical role in the diffusion of machine technology in metalworking industries (Smith 1977: 325).

Steady improvements in machine speeds, power transmission, lubrication, gearing mechanisms, precision metal cutting, and many other dimensions of performance were applied in one industrial setting after another. Industries such as textiles, arms, sewing machines, farm machinery, locks, clocks, boots and shoes, and locomotives were unrelated from the form of final product, yet very closely related from a technical perspective. Because it dealt with processes common to a number of industries, the specialized machine tool industry became a source of rapid diffusion of machine technology across the whole range of metal-using industries (Nelson and Wright 1992).

The question of why, by the end of the nineteenth century, American machine technology had come to occupy an increasingly dominant position has been intensely debated by economic historians. Ames and Rosenberg (1968) suggest an induced technical change interpretation. At lest part of the explanation lies in relative factor prices—particularly the prices of raw materials (wood and metal) and the wages of highly skilled workers relative less skilled workers. They also emphasize demand side factors such as a relatively stable American arms procurement policy, and differences in nonmilitary demand—for inexpensive utilitarian firearms in the United States versus fine sporting arms in Britain.

During the third quarter of the nineteenth century the American System, broadly defined as the mass production of precision metal components by a sequence of specialized machines, was adapted to an ever-widening range of products. The development of this new machine technology depended on a high order of mechanical skill as well as ingenuity in conception and design. Increasingly the advances were the product of a specialized machine tool industry; they were not the product of institutionalized research and development, nor did they draw in any substantial way on recent advances in scientific knowledge.[7] The advances in machine making and machine using, identified as the American System, "set the stage" for the emergence of "mass production."

MASS PRODUCTION

By the end of the nineteenth century a number of American industries had achieved high volume production—what later came to be termed "mass production." Mass production was made possible by advances in machine technology. Mass marketing was made possible by the development of a national rail and telegraph networks and a large domestic market. These industries included new branded and packaged products (cigarettes, canned goods, flour and grain products, beer, dairy products, soaps and drugs) and light machinery (sewing machines, typewriters, cameras,

[7] The period beginning in 1859 was one of remarkable scientific progress. If one had to choose any fifteen-year period in history on the basis of density of scientific breakthroughs that took place, it would be difficult to find one that exceeded 1859-74" (Mowery and Rosenberg, 1989: 22). But these advances in science were only loosely related to with advances in technology. "Relatively little of the American performance during this era was based on science, or even on advanced technical education. American technology was practical, shop floor oriented, and built on experience," (Nelson and Wright 1992: 1938).

electrical equipment) and standardized industrial machinery. Although these products were initially developed for the domestic economy many—including industrial machinery, farm equipment, and other engineering an producer goods—came to dominate international markets (Chandler 1977: 240-296). [8]

These turn-of-the-century achievements have been attributed to the confluence of two technological streams: (1) the continuing advance of mechanical and metal working skills and their application to high volume production of standardized commodities; and 2) the exploration, development, and use of the nation's mineral resource base (Nelson and Wright, 1992; 1938). Mineral discovery and extraction and advances in metallurgy drew on, stimulated, and induced some of the most advanced engineering developments of the time.[9] The oft noted complementarity between capital and natural resources in that era

[8] In this section I draw substantially on Hounshell (1984:189-302).
[9] The development of the mineral industries represented an example of the contribution of public support for science and technology in the United States. The U.S. Geological Survey under the leadership of Major John Wesley Powell was the most ambitious and successful government science project of the 19th century. Under Powell's leadership the United States achieved world leadership in the training of mining engineers and in mining practice (Nelson and Wright 1992: 1938).

was not merely an exogenous technical relationship, but was induced by a combination of natural resource abundance and rising industrial wages (Cain and Patterson, 1981). This meant that although American products were often competitive on world markets, the technology employed in their production was often inappropriate to economies with different resource endowment, or to economies in which a mass market had not yet developed (Ruttan 2001: 15-60).

Bicycle Manufacture

The American system of "mass production emerged in its most highly developed form at the Ford Motor Company in the first decade of the twentieth century. Early bicycle production, however, represented a transitional technology between the American System that emerged out of New England armory practice and the era of mass production.[10] The bicycle industry was

[10] The manufacture of bicycles in the United States began in 1878 when Albert A. Pope, a Boston merchant who had been importing English high-wheel cycles contracted with the Weed Sewing Machine Company of Hartford, Connecticut, to manufacture a American version. By the time the safety bicycle was

responsible for a number of important technical innovations that set the stage for the automobile industry, including the use of ball bearings and pneumatic tires. The most important, however, was the adoption and development of sheet steel stampings to replace drop forging and machining. In New England armory practice, drop forging and machining were the principal processes used in metal fabrication. Western Wheel Works broke from this tradition by adopting stamping technology to produce frame joints previously imported from Germany. The metal stamping equipment developed by Western Wheel toolmakers enabled it to extend the stamping technology to almost every part of the cycle and to reduce machining to a bare minimum.

The contributions of the bicycle industry to the automobile industry were not only technical. The bicycle revealed a latent demand on the part of the American public for an effective means of personal transport. It remained for the automobile industry,

introduced from England in 1887, Pope and several smaller firms had produced in the neighborhood of 250,000 high wheelers. Introduction of the safety bicycle set off a new wave of enthusiasm for the bicycle that reached its peak in the mid-1890s when the industry produced 1.2 million machines. In 1896, production by the Pope firm was exceeded by Western Wheel Works of Chicago (Hounshell 1984: 189-215).

however, to resolve the problem of assembly that would make possible low-cost mass production of a means of personal transportation.[11]

The stage had also been set for the automobile industry by the remarkable growth of the U.S. economy in the latter half of the nineteenth century. Rapid growth continued through the first three decades of the twentieth century. From 1903, the year in which the Ford Motor Company was organized, to 1926, when the last Model T rolled off the Ford assembly line, net national product grew at a rate of over 7% per year—comparable to the rates achieved by the East Asian "miracle countries" from the 1960s into the 1990s. It was this growth in consumer income, combined with the large decline in the real price of the automobile, that made the rapid growth in automobile ownership possible (Hughes 1986: 285).

[11] "The question of who built the first automobile is still a matter of dispute, but the German Karl Benz and Gottlieb Daimler were probably the first, with their gasoline-powered vehicle of 1885. Later Armand Peugot built a workable car in France, and by the 1890's the European auto industry had begun. In the United States, the auto industry dates from September 21, 1893, when the brothers Duryea of Springfield, Massachusetts, who were bicycle mechanics … built a carriage driven by a one-cylinder motor. By1899 about thirty American companies built some 2,500 automobiles for sale," (McCraw 1996: 6-7).

The Model T. Idea

Mass production at the Ford Motor Company was a product of Ford's commitment to simplicity in design and efficiency in manufacturing. The transition from production in a poorly equipped job shop to mass production was accomplished by substantial experimentation. Ford himself was a classic mechanic. He had remarkable insight about how machines worked and could be made to work better. He brought together a talented team of young engineers and executives, and encouraged experimentation with fresh ideas for gauging, fixture design, machine tool design, factory layout, quality control, and material handling. Ford production engineers tested and adapted what they found useful from New England armory practice, particularly interchangeable parts, and from "western practice," such as pressed steel parts, and added a continuous stream of their own innovations. A first step toward mass production began with eliminating "static assembly" by rearranging machine tools according to the sequence of manufacturing operations rather than by type of machine.[12] A second was the construction of a new factory at Highland Park designed to facilitate the handling of materials (Biggs 1995).

When Ford made the decision in 1909 to move to Highland Park he also made a decision that the Ford Motor Company would produce only the Model T with identical chassis for its several variants--runabout, touring car, town car, and delivery car. Workers distributed the necessary parts to each workstation and timed their delivery so that they reached the station just before they were needed. Assembly teams moved from station to station to perform specialized tasks. The first Ford assembly lines for components, such as the magneto coil, were installed in 1913. Within a year virtually every assembly operation a Ford had been put on a moving line basis. By April 1914 the time required per assembly had been reduced to just 1.5 man hours. The model T that came off the Ford assembly line represented the ultimate

[12] Rearrangement of machine tools on the shop floor became possible when tools driven by shafts and belts were replaced by tools driven by electric motors (Devine 1893: 0).

standardized machine. It was small, light, and strong, and contained a minimum of working parts.

In a retrospective article in the *Encyclopedia Britannica* Henry Ford (1926: 821-823) articulated the principles of mass production. To Ford (or his ghost writer) mass production was the method by which "great quantities of a single standardized commodity are manufactured. Mass production is not merely quantity production for this may be had with none of the requisites of mass production. Nor is it merely machine production, which may also exist without any resemblance to mass production" (Ford 1926: 821. According to Ford the essential principles were (1) the orderly progression of the commodity through the shop, (2) the delivery of parts to the worker, and (3) an analysis of operations into their constituent parts. "Every part must be produced to fit at once into the design for which it is made. In mass production there are no fitters," (Ford 1926: 822). It is doubtful that the machine tool industry could have met the standard that Ford articulated prior to 1913 (Hounshell 1984: 233).

PERSPECTIVE

The system of production that the British Commission observed at the Springfield Armory was, as noted above, quite limited before 1840. Initially only the Army was in a position to subsidize the high cost of moving materials to remote manufacturing locations such as Springfield and Harpers Ferry and to transport large numbers of finished guns to even more remote locations on the western frontier. And it was only the War Department that could provide the large arms contracts that enabled private manufactures such as North, Whitney and Colt to make the large investments necessary to build and equip factories with the machinery necessary to produce the interchangeable parts for gun production.

In his review of the history of the Frankford Armory James J. Farley concluded: “In the first half of the nineteenth century the Ordnance Department, rather than private industry, directed the evolution of the American System of manufacture. It pioneered both uniformity and interchangeability,” (Farley 1994: 48). The emergence of an independent machine tool industry in the United States around the middle of the 19th century and of mass production in the first decades of the 20th century were the direct consequences of the investment by the War Department during the first half of the 19th century in the invention of armaments, in the development of machines, and of machine methods of manufacturing.

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