Texto para Discussão 021 | 2023

Discussion Paper 021 | 2023

Money and the Market and the Military Origins of the American System

Nicholas Trebat

Instituto de Economia, Universidade Federal do Rio de Janeiro

Money and the Market and the Military Origins of the American System

September, 2023

Nicholas Trebat

Instituto de Economia, Universidade Federal do Rio de Janeiro

Abstract

This article discusses the development of mass production technology in the United States. Like spaceflight and the computer, this technology grew out of a state-led effort to promote technical progress in weapons and defense production, giving rise to what was known in the 19th century as the “American System of manufactures”. Though the roots of this system in military-industrial policy are well-established, economists continue to suggest technical progress in 19th century America was a market-driven affair, led by entrepreneurs eager to reduce production costs and obtain patents. We offer a different perspective, based on extensive historical research existing on this topic. We discuss the origins of interchangeable parts technology in Europe, its early development in the United States, and its diffusion to consumer goods manufacturing after 1850. We also reflect on the reasons for the United States War Department's interest in this technology after 1800.

Keywords: Technology, machine tools, mass production, military procurement.

JEL codes: N0, N1, N4, N7.

Introduction

Industrial progress in the 19th century United States is widely attributed to the emergence of the “American system of manufactures”, a term coined by British visitors in the 1850s referring to manufacturing techniques characterized by the use of precision machinery and a complex division of labor. The American System was indeed a major historical development: it was the predecessor of modern mass production technologies. As Nathan Rosenberg (1977, p. 23) observed, the study of technical change in 19th century America requires an analysis of “those sectors usually regarded as defining what was so truly special about our technological history—the mass production of standardized products consisting of interchangeable component parts…a system so different from anything known in Europe that…it was widely referred to there as ‘The American System of Manufacturing’”.

For generations, economic historians have argued the American System was a market-driven phenomenon rooted in unique economic, cultural and institutional conditions in the United States favoring the development of mass production techniques. Natural resource abundance, high wages, and a relatively egalitarian distribution of income, it is argued, encouraged American firms to substitute machines for skilled labor and introduce innovations such as interchangeable parts manufacturing (Rothbarth 1949; Habakkuk 1962; Rosenberg 1977; David 2004). The relative absence of trade unions in the United States, furthermore, combined with a low-cost patent regime, among other “cultural and institutional factors” (Goodfriend and McDermott 2021, p. 36), stimulated the invention and diffusion of mass production techniques.

America’s market-oriented approach to interchangeability would explain why this technology flourished in the United States rather than in France, where earlier efforts to promote this technology were driven by military concerns. France’s statist, military-oriented approach “contrasted sharply with American practice, in which money and the market drove the search for interchangeability and progress took place in a wide range of industries” (Landes 1999, p. 303).

Mainstream scholars assign a relatively minor role to the public sector in the development of mass production technologies. This, we argue, constitutes a significant oversight. Like spaceflight and the computer (Medeiros 2004), the American System grew out of a state-led effort to promote technical progress in weapons and defense production. After decades of improvement through military sponsorship, consumer goods manufacturers were finally able to adopt the methods of interchangeable parts manufacture more fully.

Though the roots of the American System in military-industrial policy are well-established (Hounshell 1984; Smith 1987), the influence of the traditional approach remains strong (Goodfriend and McDermott 2021). Mainstream theorists continue to promote the idea that "money and the market" drove technical advance in 19th century America, the public sector contribution being limited essentially to protecting property rights (Acemoglu, Moscona and Robinson 2016). Lacking are accounts that draw on the diverse historical research that exists on this topic, and attempt to clarify the inadequacies persisting in the economic literature. That is the objective of the present research.

This article contains six sections, in addition to this introduction. The first discusses the traditional approach in more detail, highlighting some of its shortcomings. The remaining sections offer an alternative approach. Section 2 comments briefly on technological developments in 18th and early 19th century Europe, of which the American System was a direct descendant. Section 3 discusses the early development of interchangeability in the United States, analyzing some of the reasons for the War Department's interest in this technology. Section 4 discusses the role of federal procurement policy in encouraging the use of mass production techniques, while section 5 analyzes the adoption of these techniques in civilian manufacturing sectors after 1860. The final section concludes the paper.

Section 1: The Traditional Approach to the American System

The traditional approach to the American System argues its rise was attributable to unique aspects of American factor endowments (capital and labor) and consumer demand. The basic argument, pioneered by Rothbarth (1946) and Habakkuk (1962), is that greater availability of land and natural resources in the United States drove up wages relative to

Britain, encouraging firms to innovate with capital-intensive production methods as a means of lowering production costs[1]. Elaborating upon this argument, David (1975, p. 87-8) argued that 19th century machinery consumed large amounts of raw material such as wood, hence greater access to cheap raw materials supplies made it less costly for American firms to use and experiment with machine-based methods of production. These incentives resulted in higher capital-output and capital-labor ratios in the United States, setting off a learning process that culminated in the rise of mass production techniques (David and Abramovitz 2001, p. 148; David 2004, p. 10-11).

Mass markets for consumer goods and greater wealth and income equality, relative to Western Europe, allegedly played a key role in this process, for they implied a greater homogeneity of consumer preferences in the United States, encouraging firms to produce standardized goods with interchangeable parts. "Important to permitting this form of production was the scale of the demand for products and the impact of a relatively equal distribution of income upon the structure of demand" (Engerman and Sokoloff 2000, p. 378). Mass production technology was "encouraged by the [United States'] higher and more widely diffused incomes…By contrast, Europe's lower and less equally distributed incomes initially restricted the market for [standardized] goods to its well-to-do classes…and thereby delayed the full application of American mass production methods" (David and Abramovitz 2001, p. 148-9).

Various cultural and institutional factors are also believed to have encouraged mass production techniques. The "intelligence, ability and self-reliance of [American] mechanics" (Ferguson 1962, p. 15), combined with the absence of workers' guilds, stimulated "inventive activity" and the sharing of technical knowledge. A democratic, low-cost patent system lowered financial barriers to innovation and allowed a market for patent licenses to flourish, facilitating the transfer of American System techniques across firms and industries (Goodfriend and McDermott 2021, p. 36).

Before turning to a critical analysis, brief remarks of a theoretical nature are in order. Access to cheap wood, iron ore, and energy supplies certainly benefitted American

[1] Temin (1966), David (1975) and Rosenberg (1977), among others, offered important later contributions.

manufacturers over the course of the 19th century (Irwin 2000), and no attempt will be made here to assess the claim that the machine technologies of this period consumed large amounts of such resources. Nor will it be denied that relatively high wages can drive mechanical innovations by encouraging firms to save on labor costs. Indeed, the notion that wage growth, and class conflict more generally, stimulates technical change did not originate with the economic historians surveyed here, figuring prominently in the writings of Ricardo ([1817] 1951) and Marx (1887), as well as Hicks (1963), Braverman (1974) and Labini (1977), among others. Control over the workforce is a key variable in the capitalist division of labor, and firms tend to use technology in ways that strip skills and decision-making power away from production workers in order to concentrate power and profits within management. Braverman (1974) offered clear examples of this in his analysis of the spread of mass production techniques in the 20th century. The use of robotics and digital technologies in manufacturing and services industries today provides further examples.

Nevertheless, there is an important difference between the capitalist decision to innovate, on the one hand, and the process by which revolutionary technologies such as computers or nuclear power emerge on the other. The simple logic of "money and the market" (see Introduction) could never have resulted in technologies such as these, for they took years, often decades, to develop, and involved massive costs and collective effort well beyond the means and ambitions of profit-oriented firms.

The market-oriented approach to the rise of the American System cannot come to terms with several well-known facts. Resource abundance, a democratic patent system, and homogeneous consumer preferences are broad macroeconomic and institutional features affecting the economy as a whole. Thus, one might expect, had these features been in fact decisive, mass production techniques to have evolved gradually and in a wide range of industries; or at least more than one. This was not the case. Almost all of the basic machines, equipment and procedures required for interchangeable parts manufacturing originated in a single industry between 1810 and 1840, and were only adopted by other manufacturing sectors in the United States after decades of refinement. Armaments production can be "properly regarded as the original home of mass production technology" (Rosenberg 1977, p. 23-4). Or, as Roe (1916, p. 144) noted in his classic history of British and American machine tool makers: “In sketching the development of interchangeable methods in American shops, we have confined our attention to gun makers...They were by no means the only ones to have a part in this development, but they were its originators, they determined its methods, and developed most of the machines typical of the process.”

There is no evidence, furthermore, to suggest American manufacturers were more capital-intensive (that is, used production techniques with higher capital-labor ratios) than British ones prior to 1860. To the contrary, there is strong evidence that British firms were the more capital-intensive (Field 1985; Irwin 2000), a result that holds even if one restricts the definition of “capital” (which may include structures such as buildings) to machines and machinery services. “British capital-labor ratios were not lower than the corresponding American ratios in 1860. They were higher. Even with respect to manufacturing machinery considered alone…Britain used more machinery services per unit of manufacturing output and per unit of manufacturing labor than did the United States” (Field 1985, p. 388). Irwin (2000) finds that the value of capital per worker in the United States was below that of Britain as late as 1879.

The myth concerning greater American capital intensity derives most likely from a superficial interpretation of British government reports on American manufacturing published in the mid-1850s. In 1854, the British Parliament sent a group of observers to the United States, including prominent engineers, to inspect manufacturing establishments in this country. Based on the inspectors’ accounts, the British Board of Ordnance published a report referring to an “American System of manufactures” (this is the origin of the term) characterized by the use of a variety of automatic, sequentially-operated machines.

American machinery “employed by engineers and machine-makers…are whole behind those of England”, the report observed, but “in the adaptation of special apparatus to a single operation…the Americans display an amount of ingenuity, combined with undaunted energy, which as a nation we should do well to imitate.” “Among the many trades to which these remarks apply”, the report added, “that of small arms stands conspicuous” (Cesari 1970, p. 329).

As can be inferred from this quote, there is little evidence, either in the British reports or elsewhere, to substantiate the notion that American machinery was generally superior to British machinery at this time. Habbakuk (1962, p. 5) himself noted that "[i]n many and probably in most fields of technology the English were still far ahead of the Americans". Export figures reinforce this impression: British manufacturers, not American ones, dominated world markets for machinery and iron and steel products in the 19th century. American machinery exports were relatively insignificant prior to 1890 and grew slowly in this period (Floud 1974, p. 62). Saul (1967, p. 114) notes that British textile machinery and marine engines of the late 19th century were not only superior to American models but produced to a greater degree of standardization.

American machinery exports increased rapidly in the 1890s, a period which marked the coming of age of American manufacturing. Before this, American superiority seems to have been limited to a relatively small group of "ingenious" machines (Floud 1974, p. 67) used in arms production as well as woodworking[2].

With regard to the effect of mass markets and consumer preferences on production methods in the United States, it is important to recall that this country only surpassed

---

[2] The lack of clear evidence of a broad American superiority in machinery production leaves unexplained the finding, about which there is broad consensus in the literature, that labor productivity in American manufacturing was higher than in Britain in the 19th century. Much of the initial reason for scholarly interest in the American System was precisely because it appeared to offer an explanation for this productivity lead. Though this is not the place for a detailed investigation, it is important to keep two things in mind: first, the British manufacturing sector in the mid-19th century was much larger than the American one, both in terms of output and employment (Broadberry and Irwin 2004, p. 21-3). In other sectors, such as mining and construction, Britain had a substantial labor productivity lead. It is likely, then, that some of the difference in labor productivity is due to differences in the size and composition of British and American manufacturing, with a large presence in the latter of high productivity sectors (such as, say, food and lumber products) that were much less relevant in Britain. Second, the U.S. lead in manufacturing productivity has been documented since at least 1840, predating by several decades the adoption of American System techniques by consumer goods producers. Thus, even if the rise of the American System reflected some broad tendency favoring the adoption of scale- and capital-intensive techniques in the U.S., this tendency cannot explain the U.S. productivity lead in manufacturing. It may be the case that the use of superior machines in certain sectors of the U.S. economy helps explains part of this lead, but the only piece of American machinery that appears to have been considered superior in the mid-19th century were the special-purpose machine tools developed in the arms industry.

Britain in population size in the mid-1850s, and only surpassed Britain in terms of real GDP around the 1860s (Bolt and Luiten van Zanden 2020). It is thus not clear how "the scale of the demand" (section 1) for consumer goods could have been a critical factor in the early development of mass production technologies, since, during this time, the British economy and its consumer base was roughly as large, if not larger, than the American one.

It is also not clear to what extent wealth and income were more equally distributed than in Great Britain. The United States was certainly never a society "free…of the class and status" distinctions prevailing in Europe, a characteristic Landes (1999, p. 301) claims was instrumental in the development of interchangeable parts technology. It is worth recalling that the wealthiest region of the United States in the first half of 19th century was a slave society, so large that slaves accounted for over 25% of the American labor force (Lebergott 1966). Moreover, roughly 50% of European immigrants to North America during the 18th century arrived as indentured servants (Grubb 1994, p. 794), suggesting colonial and early post-independence America was not dramatically more egalitarian than Western Europe. Roine and Waldenstrom (2004) offer evidence confirming this impression, showing income distribution in early 19th century England and the United States was roughly the same. Lindert and Williamson (2016) disagree, arguing colonial America was significantly more egalitarian than Western Europe. But even this study finds inequality rose sharply in the US between 1800 and 1850, reaching British levels by midcentury. This is problematic for the mainstream approach, for mass production techniques were not widely-adopted in consumer goods manufacturing until well after 1850 (section 4).

Section 2: Machine Tools, Military Strategy, and the Origins of Interchangeability: 1700-1800

The modern concept of interchangeability originated in France in the 1760s, notably with French General Jean Baptiste de Gribeauval, whose principle of "uniformity" was backed financially by the monarchy. By the early 1780s, French manufacturers were producing gun carriages and locks to what were then considered impressive degrees of interchangeability. The precision work was performed by skilled manual laborers equipped with hand tools, and such methods would persist in French (and British) manufacturing through the mid-19th century. The notion of machine-produced interchangeable parts was then regarded, even by prominent scientists and engineers, as farfetched, or simply impossible (Hounshell 1984, p. 40).

Official support for "le système Gribeauval" weakened after the French Revolution, after which French progress with interchangeability in firearms production appears to have stalled. One reason for this lack of progress, beyond the lack of government support, was that the machine tools capable of performing the precision cuts demanded by interchangeable manufacture had not yet been invented. Roughly fifty years would pass before industrialists and engineers perceived that large-scale interchangeable parts manufacture could only be achieved through the use of machinery.

Modern general-purpose machine tools were largely British inventions of the late 18th and early 19th centuries, dramatically increasing the accuracy of turning and drilling operations with wood, brass, and metal[3]. Without such advances, Marx (1887, p. 262) famously noted, modern machinery would have retained a "dwarfish character", crippling industrial progress. In the case of the steam engine, its inventor (James Watt) took years to bring the innovation to market due to difficulties encountered in accurately drilling pistons out of metal. The solution emerged in 1774 with the development of the cylinder lathe, a machine tool originally designed for producing naval ordnance.

Machine tool progress had a self-reinforcing character, in the sense that technical obstacles to the production of better machine tools required the development of more powerful, more accurate tools to shape and cut metal. Ayres (1988, p. 91) relates this to the history of interchangeable parts: "The long delay in achieving the interchangeability of parts was due to these interrelated barriers. The later success of the automobile could

[3] General-purpose machine tools are power-driven machinery used to shape and cut iron, brass, wood, and other hard surfaces. Special-purpose machine tools are built to follow more specific machining instructions; the shapes and dimensions of parts to be machined are built into the hardware or software of the machine. This is what makes special-purpose machine tools appropriate for mass production of interchangeable parts.

not have occurred, in turn, without the prior existence of a sophisticated machine tool industry."

Machine tool progress in 18th and early 19th century Europe was often a response to problems encountered in weapons and defense production. "[I]n almost every country there were huge arms works [where] metals and new machining techniques were often pioneered...partly because the technical requirements were high and partly because cost was not always the key factor" (Milward and Saul 1979, p. 225). Technical advance in these often state-owned arms factories were not a means for reducing cost or increasing profit, but the very goal of production itself.

As noted above, the cylinder lathe had its origins in arms production. Its inventor was a British military contractor with years of experience dealing with similar problems in the boring of naval cannon. "After a decade of work on military ordinance, John Wilkinson developed a cannon lathe that, in addition to making better artillery, was able to bore cylinders accurately enough to make Watt's steam engine work" (Page 2015, p. 95).

Though originating in France, the most important sponsor of interchangeable parts technology prior to 1810 was the British Navy. In the early 1800s, it hired Henry Maudslay and Marc Brunel, early pioneers of mass production techniques, to build a system of machinery to produce wooden pulley blocks[4] at the royal dockyard at Portsmouth. Maudslay and Brunel transformed the dockyard into "the first full-scale factory in the world to use machine tools for mass production" (Coad 2005, p. 49). By 1808, the dockyard was responsible for the British Navy's entire supply of pulley blocks, producing 130,000 units a year and constituting "the world's first factory where power-driven machine tools set the pace, dictated the layout and carried out nearly all the manufacturing processes" (Coad 2005, p. 75).

The Portsmouth machinery represented an early breakthrough in the industrial application of interchangeability, and played a key role in the invention of the Blanchard lathe, a complex set of automatic machine tools invented by American engineer Thomas

[4] Pulley blocks are lifting tools used on ships to lift and give direction to sails.

Blanchard in the 1820s (Hounshell 1984, p. 35). The Blanchard lathe was a central feature of the American System. Unlike other elements of this system, it was quickly introduced into civilian manufacturing, notably woodworking (section 3).

Section 3: Early Developments in the United States: 1800-1840

Extensive research (Hounshell 1984; Smith 1987) shows that the United States (U.S.) War Department, precursor to the Department of Defense, introduced the concept of interchangeability in American manufacturing in the 1790s and heavily subsidized the early development of mass production techniques[5]. Most innovations related to interchangeable parts manufacture were introduced after the War of 1812, but the groundwork was laid earlier. From 1794 to 1812, the War Department implemented several policies vital to the development of the American System, the most important of which was the construction of the federal arms factories at Springfield, Massachusetts and Harper's Ferry, Virginia. Symbols of manufacturing excellence, these federal armories were firmly committed to the French "uniformity principle" (section 2), and were by far the largest arms producers in the United States prior to the Civil War.

The War Department's interest in interchangeability sprang from two main sources: a strong desire to improve military capabilities, and the influence of pre-revolutionary French military strategy. France had played a decisive role in America's war of independence, and the withdrawal of its weapons and troops after 1783 left the federal government in a difficult situation: one of its main objectives was to seize land west of the Appalachian Mountains, but the continued presence there of British troops, allied with Native Americans forces, impeded them from doing so. It was to meet this challenge that

[5] Textile manufacturers played a relatively minor role in the development of modern machine tools. Though most machine tool producers in the US began as subsidiaries of textile firms, the lathes and planers built by these companies did not provide the speed and precision necessary to mass produce interchangeable parts.

the War Department was created in 1789, centralizing military power in the hands of the federal government.

America’s military difficulties continued through the War of 1812, during which British troops occupied the capital and burned much of it to the ground. Deficiencies in the quality of firearms were regarded as one of the army’s main weaknesses. This context provided political backing and ample resources for federal investments in weapons production.

Having served as military advisers during the war of independence, many French officials emigrated to the United States after the French Revolution, becoming ranked officers. One of these, Louis de Tousard, was instrumental in the decision to build the military academy at West Point, modelled on French military principles and America’s premier engineering school throughout the 19th century. Tousard was a strong advocate of Gribeauval’s “system of uniformity” (section 2).

Though waning in France, the Americans’ interest in this system would remain strong. They had witnessed its strategic value during the battle of Yorktown, the decisive land battle of the war of independence, in which the mobility of French artillery had proved vital. Thomas Jefferson served as ambassador to France during the war and had visited French gun workshops personally, notably that of interchangeable parts pioneer Honoré Blanc. After the French National Assembly rejected Blanc’s request for continued government sponsorship, Jefferson suggested his factory be relocated to the United States (Smith 1987, p. 47).

In 1798, the War Department made a cash advance to the private gun factories of Simeon North and Eli Whitney for 10,000 muskets with interchangeable parts. This was an enormous quantity, considering that, forty years later, annual arms production at the federal armories was just over 22,000 (Rosenbloom 1993, p. 688). Such advances, Deyrup (1970, p. 66) noted, brought America’s private “[arms] industry into existence”.

In 1815, Congress gave responsibility for weapons production, both public and private, to the War Department’s Board of Ordnance, authorizing the Board to "draw up a system of regulations...for the uniformity of manufactures of all arms ordnance, ordnance stores, implements, and apparatus..." (Smith, 1987, p. 44). Between 1794 and 1815, the Springfield Armory instituted a complex division of labor and introduced precision instruments to measure the conformity of its firearms with fixed specifications. By 1825, Springfield had become “an even more important prototype of the modern factory than the integrated textile mill” (Chandler (1993, p. 72-3).

Machine tool progress accelerated after 1812. In 1813, the War Department awarded Simeon North a contract for 20,000 pistols, stipulating that the component parts be “so exactly alike that any limb or part of one pistol may be fitted to any other pistol of the 20,000” (Hounshell 1984, p. 28). While attempting to fulfill this contract, North invented the milling machine, the first major innovation of the American System.

War Department officials quickly introduced the milling machine at the Springfield and Harper’s Ferry armories, reflecting the War Department’s “implicit understanding with all arms contractors that they had to share their inventions with the national armories on a royalty-free basis if they wished to continue in government service” (Smith 1987, p. 78). “Such an ‘open door’ policy”, Smith (1987, p. 78) notes, “explains why so few crucial machines and machine processes were actually patented during the antebellum period”.

The next step in the development of interchangeable parts manufacture was the invention of the Blanchard lathe. This set in motion a period of rapid progress in machine tools and revolutionized the production of shoes, chairs, ax handles and wagon wheels. Thomas Blanchard, who had studied descriptions of Maudslay and Brunel’s woodcutting machinery at the Portsmouth dockyards (section 2), invented a primitive version of his lathe in 1818 while building wooden musket barrels for the Harper’s Ferry Armory. The Springfield Armory then hired him as an inside contractor, giving him the income, raw materials, and power supply needed to perfect his machine. By 1825, the final version was complete. Blanchard’s sequentially-operated machinery practically eliminated hand labor in the making of gunstocks: “It is this sequential operation of special-purpose machines which characterized mechanization in American manufacturing” (Hounshell 1984, p. 35).

Gunstocking machinery based on the Blanchard lathe was the piece of equipment that most impressed the British observers in the 1850s (see Introduction), and the British government imported large quantities of it for use at its Enfield arsenal, a public arms factory built in 1855 and modelled on the Springfield Armory. The Blanchard lathe was considered "so spectacular that it was the only machinery that that the [British government]…ordered without comparing alternate uses for their funds" (Temin 1966, p. 282).

The federal arsenals also sponsored the work of John Hall, an inside contractor at Harper's Ferry who worked extensively with Simeon North and mechanics at Springfield. Hall's main contribution to the American System was to unite the concepts of mechanization and interchangeability. Hall's work convinced the War Department, which had also invested heavily in craft methods, that machines and precision instruments were the keys to turning the French concept of "uniformity" into a reality.

There is no evidence that American System techniques were cost-efficient in the mid-19^{h} century. Production costs at large gun factories were very high compared to civilian manufacturing, and this was consistent with the War Department's stated goal, which was not to minimize cost but to produce large amounts of weapons with interchangeable parts. Hounshell (1984, p. 44) notes that had it been possible to achieve this goal relying on hand labor, the War Department would have done so. "[T]he War Dept never really expected significant cost reductions. Yet it achieved its long-sought goal of solid, easily repairable weapons constructed with uniform parts…It was willing to achieve that goal through hand labor…or by machines." (Hounshell 1984, p. 44).

By the mid-1830s, the American Northeast had become a sophisticated manufacturing complex based around the Springfield Armory. Six of the country's eight largest private arms factories in 1840 were located in New England relatively close to the armory—two in Massachusetts, three in Connecticut, and two in Vermont. War Department officials encouraged inventors and manufacturers of any kind to visit and draw designs of the machines and equipment in use at the federal armories (Smith 1987, p. 54).

The Ames Manufacturing Company, a machine tool manufacturer which played an important role in the diffusion of mass production techniques, was established in 1834 a few kilometers away from the Springfield Armory. Its engineers had "ready access to patterns and drawings owned by the national armory" (Smith 1987, p. 78), as well as access to the armory's skilled labor. The company produced milling machines and by the 1850 was the exclusive supplier of gunstocking machinery to the Springfield Armory, machinery, Cesari (1970, p. 123) notes, "based on the Blanchard lathe [and] developed at the Armory's expense some three decades earlier". Smith (1987, p. 77) adds that "despite their obvious technical skill and versatility", Ames' founders "were basically copyists rather than innovators".

Ames, Colt Armory, Browne and Sharpe, Robbins and Lawrence, Providence Tool, Remington, Pratt and Whitney and other gun and machine tool manufacturers were part of a tight network of War Department contractors in which the flow of knowledge and techniques was intense. George S. Lincoln and Company, also based in the Northeast, successfully marketed the Lincoln miller in the 1850s, a milling machine based on an earlier model built by Frederick Howe of Robbins and Lawrence. Howe had worked for Simeon North, and based his new milling machine on a model then in use at the Springfield Armory (McNeil 1990, p. 408).

Prior to the emergence of such firms, there was no specialized machine tool sector in the United States. War Department demands led to the emergence of a "separate [machine-producing] industry consisting of a large number of firms most of which confined their operations to a narrow range of products— frequently to a single type of machine tool…" (Rosenberg 1963, p. 427). This industry, originally a cluster of firms located in close proximity to the federal armories, acted as a conduit in the spread of mass production techniques to civilian manufacturers (section 5).

Section 4: The Role of Procurement Policy

Almost all of the firearms and machine tool manufacturers responsible for the development of mass production techniques in the mid-19th century were large military contractors. The turret lathe, a descendent of Blanchard's machine, was built by Stephen Fitch while fulfilling a contract to produce 30,000 gunlocks for the US Army in 1845, just prior to the Mexican-American War. This machine eliminated the need to manually adjust the position of metal parts during cutting operations, transforming manufacturing processes dependent on large quantities of small parts such as locks and screws (McNeil 1996, p. 410).

The double-turret lathe was introduced in 1852 by a mechanic at the Colt Armory, and the Jones and Lamson company, formerly Robbins and Lawrence (section 3), began selling the machine commercially in 1858. "From this point on, the machine was adapted and modified for innumerable uses in the production of components for such products as sewing machines, watches, typewriters, locomotives, bicycles and, eventually, automobiles" (Rosenberg 1963, p. 429).

As suggested in section 3, production costs at large gun factories were prohibitively high for consumer durables manufacturers in the 1850s. There is no record in this period of advanced precision techniques in use even by small arms producers. "Virtually all of the private producers who appear to have been capable of employing the methods of the American system in 1840 were producing guns for the United States military" (Rosenbloom 1993, p. 691).

U.S. Census reports identify six of the eight private factories producing more than 1,000 firearms in 1840. Of these six, four had federal contracts. The two remaining companies declared bankruptcy in 1842, one of which was Colt Patent Arms Manufacturing, Samuel Colt's first arms company. It went bankrupt due to quality issues and a "lack of public and government support" (Rosenbloom 1993, p. 691). Colt re-entered the arms business in 1847, after being awarded an Army contract for 1,000 pistols.

A comparison of American and British arms procurement policies is enlightening. In the 1850s, the British military still relied for its small arms needs on a decentralized network of private manufacturers located mainly in Birmingham. Orders placed with individual producers were relatively small and work was contracted out to skilled craftsmen. Asked by a British parliamentary committee in 1854 why English gunmakers used less machinery than their American counterparts, a prominent gunsmith responded that the problem was the lack of "stable rates of military procurement", adding that, had the British government placed larger, long-term orders, arms manufacturers would have had no choice but to mechanize. “If you had [500,000] guns to make a year, would you introduce machinery”, asked the committee. “I could not make them without”, he responded (Ames and Rosenberg 1968, p. 838). Prior to the mid-1850s, “[t]he British Government apparently did little, if anything, to moderate the extreme instability which its contracting procedures imposed upon the gunmaking industry, or to enable the industry to operate with a longer-term planning horizon” (Ames and Rosenberg 1968, p. 832).

Quality concerns likely explain the British government’s hesitance to promote American arms making techniques. Consumer goods manufacturers, both British and American, shared these concerns, and showed a similar reluctance to adopt the American System.

Section 5: Diffusion after 1860

The spread of mass production techniques to civilian sectors of the U.S. economy was a process spanning the period between 1840 and 1890. It was restricted, for the first forty or so years of this period, to a very small group of industries, the key sectors, in chronological order, being firearms and machine tools, sewing machines, bicycles and, finally, automobiles.

Machine tool producers played a fundamental role in the diffusion of the American System. They “became learning centers where metalworking skills were acquired and developed, and in which knowledge about precision manufacturing was incorporated and “transferred to the production of a sequence of new products—interchangeable firearms, clocks and watches, agricultural machinery, sewing machines, typewriters, bicycles, automobiles” (Rosenberg 1977, p. 24).

As a result of certain features common to all manufacturing processes, products that appear very different, such as guns and sewing machines, are in an engineering sense very similar. The tools and techniques used in one industrial sector can thus be transferred easily to other sectors. Rosenberg (1963, p. 423) called this feature of industrialization “technological convergence”, and it allowed the concept of interchangeable parts manufacture, originally developed for use in a single industry, to be applied to a wide range of other industries.

As noted in section 4, private firms such as Ames Manufacturing and Remington began marketing their machine tools to consumer durables producers as early as 1840, and themselves moved into the production of sewing machines and typewriters in the 1850s. Remington, which produced rifle barrels for the U.S. Army, began producing sewing machines in 1870, and typewriters in 1874.

The sewing machine industry was responsible for important machine tool innovations based on earlier special-purpose lathes and milling machines. Essentially non-existent in 1850 (the sewing machine was first patented in the United States in 1846), by 1860 the industry was larger in terms of output and employment than the firearms industry itself (U.S. Census 1865, p. 740). Sewing machines had a tremendous impact on the productivity of other sectors, notably boot and shoe manufacturing, which in 1860 was the country's largest manufacturing employer (U.S. Census 1865, p. 733).

America's three largest sewing machine companies, Wheeler and Wilson, Wilcox and Gibbs, and Singer Manufacturing, were founded in the early 1850s. The first two had close ties to the arms industry and adopted mass production techniques from the outset. Wilcox and Gibbs in fact outsourced all of its sewing machine production to Brown and Sharpe (section 3). Brown and Sharpe would continue to produce sewing machines for Wilcox and Gibbs until the 1950s, and would be responsible for numerous innovations, originally intended for sewing machines, but with universal applications to other industries.

Wheeler and Wilson's factory was located close to the Colt arms factory in Bridgeport, Connecticut, from where it hired its first machinists and production supervisors. Joseph Alvord, a Wheeler and Wilson employee and important figure in the development of mass production techniques, had been an apprentice of Nathan Ames, founder of Ames Manufacturing. He had worked for eight years at the Springfield Armory and had also worked for Robbins and Lawrence. A specialist on the history of the Singer Manufacturing Company noted in the 1920s that "many principles of tool building that

[Alvord] introduced into the early history of sewing machine work…are now the regular procedure in the art of tool building" (Hounshell 1984, p. 71).

Among the most important machine tool innovations arising in the sewing machine industry were the automatic screw machine, a lathe invented by a former Colt employee, and the universal grinding machine, invented by a mechanic at Brown and Sharpe, Henry Leland. Leland's career is an interesting example of the American System's development: he began his career as a tool builder for the Springfield Armory, then worked at the Colt Armory before moving on to Browne and Sharpe. He then founded a company that made bicycles and marine engines in the 1890s, before founding, in 1902, the famous Cadillac Motor Company.

For the first ten years of its existence, the universal grinder was used in producing guns, iron, woodworking tools, textile machinery, cutlery, and machine tools themselves. The universal miller, a milling machine developed by Brown and Sharpe, was used in the manufacturing of cash registers, calculating machines, typewriters, agricultural implements, bicycles and automobiles, among others. It "was to become the most flexible and widely used machine tool, second only to the lathe…" (McNeil, p. 408).

Bicycle manufacturers took mass production techniques to the next level in the 1890s, introducing innovations such as ball-bearings, sheet metal stamping and electric-resistance welding. By 1900, mass production techniques could be profitably applied to automobile production. The automobile industry depended heavily on prior developments in sewing machines and bicycle manufacturing. "The transition to automobile production …was therefore relatively easy, because the basic skills and knowledge required to produce the automobile did not themselves have to be 'produced' but merely transferred from existing uses to new ones. This transfer was readily performed by the machine tool industry" (Rosenberg 1963, p. 437).

Hounshell (1984) dispels the assumption that clockmakers or manufacturers of agricultural machinery were key figures in the development of interchangeable manufacture, as some scholars suggest. The McCormick Harvesting Machine Company, which David (2004, p. 10-11) claims brought "the methods of production by interchangeable parts…to full practical realization", only adopted mass production techniques in the early 1880s after hiring a superintendent with experience in firearms and sewing machines. Compared to arms and sewing machine manufacturers, the McCormick factory was backward, employing "almost no special- or single-purpose machinery…there is little evidence that [the owners] knew of the techniques…which distinguished the arms industry" (Hounshell 1984, p. 7).

Singer Manufacturing was also relatively slow in adopting "armory practice" (Hounshell 1984, p. 5). As late as the early 1880s, Singer sewing machine parts were not interchangeable, and final assembly relied heavily on skilled labor. Like shoe manufacturers and woodworking firms in the mid-19th century, Singer did employ some of the machinery typical of the American System, but there was a difference between its methods and those of large machine tool and gun factories. Compared to consumer goods producers, the latter resembled scientific laboratories, relying on expensive, sequentially-operated machines in conjunction with precision instruments designed to minimize human error. This was a still developing system of production in the mid-19th century, and the vast majority of American firms were skeptical of its relevance and unwilling to incur its high fixed costs.

This skepticism was shared by renowned engineers such as Britain's Joseph Whitworth, who doubted whether machines could ever be capable of producing interchangeable parts without the aid of skilled labor. The American System was widely-regarded as an efficient way to quickly produce large amounts of guns, but not everyone in the 1850s was convinced that it was capable of producing guns at a lower cost, or with the same quality, as those made by traditional methods. British specialists in particular argued the parts of American guns were not as well finished as British rifles, and attributed this to superior hand work performed on the latter (Hounshell 1984, p. 21).

Similar doubts would exist in consumer goods industries for decades to come. In 1870, Singer outsourced sewing machine production to Providence Tool (section 3), but terminated the contract soon after, as management deemed its techniques "sloppy", arguing hand filing was necessary to produce a high-quality sewing machine (Hounshell 1984, p. 99).

19th century Singer sewing machines, it is important to note, were not low-priced, and its original sales strategy was not based on flooding the market with cheap, standardized goods. To the contrary, the company, like McCormick, "sold the most expensive products in their respective industries" (Hounshell 1984, p. 9), relying on its marketing department to corner domestic and especially international markets.

The steady increase in sales and in the geographical range of customer bases in the late 19th century, Hounshell (1984) argues, convinced Singer and other civilian manufacturers to abandon craft methods and adopt mass production techniques more fully[6]. Singer's predicament was typical of the industrial age (Hirschhorn (1986, p. 9):

Interchangeability is fundamental to the entire industrial apparatus. Products must be sold on a mass scale to mass markets, and the consumer cannot return to the point of manufacture for replacement or maintenance. Rather, a separate parts economy must evolve so that the consumer (or the secondary producer) can confidently purchase a part that will fit the original product or machine. Mass marketing depends on mass interchangeability.

In Singer's case, the definitive step towards interchangeability was taken in the late 1870s and early 1880s. Standardized parts, managers realized, facilitated not only large-scale production, but also product repair and sales in increasingly distant regions. This is hardly surprising: it was for broadly similar reasons that military strategists had conceived of the idea of interchangeable parts more than a century earlier.

The modernization of Singer's production techniques was part of a broader phenomenon not restricted to the sewing machine industry or to the United States, as evidenced by the boom in American machinery exports to Western Europe in the 1890s. Interchangeable parts technology had reached maturity.

[6] We suspect, following Braverman (1974) and Noble (1984), that an eagerness to deskill the manual labor force played an important role here as well.

Section 6: Conclusion

For generations, economic historians have attempted to explain why modern interchangeable parts technologies emerged in the United States rather than in Britain, birthplace of the Industrial Revolution. The dominant approach to this question focuses on wage differences and natural resource constraints, which, it is argued, offered greater incentives for American firms to substitute machinery for skilled labor. Scholars have also emphasized institutional factors such as a low-cost patent regime and the relative absence of trade unions in 19th century America, which are believed to have facilitated knowledge transfer and stimulated innovation.

These arguments are no more useful in understanding the early development of interchangeable parts technology than they are in explaining the origins of the atom bomb. Interchangeability was a concept devised not by inventors seeking patents but by military strategists seeking advantages on the battlefield. This was roughly a century before the concept was applied to the production of consumer goods. There was nothing rational, from a cost perspective, about the pursuit of interchangeable parts manufacture in the mid-19th century. Precision techniques were expensive, and serious questions remained as to their technical and economic feasibility. Not even private gunmakers producing for civilian markets in 19th century America could afford the methods of the federal armories. Those who did so did this not because it was cost-efficient, or because they had incentives to mass produce standardized consumer goods, but because they were military contractors whose client demanded it.

The War Department was in a unique position to a sponsor mass production techniques in the early 19th century: it had been given ample financial resources and a mandate to promote technical progress in firearms production. It was also the inheritor of a military philosophy—the uniformity system—whose most enthusiastic sponsors had been removed from power by the French Revolution, leaving the United States as perhaps the Western military power most actively pursuing the goal of interchangeability. This, we believe, sheds light on how the War Department brought to maturity what was to become the dominant production technique of the 20th century: machine-based interchangeable parts manufacturing.

References

Acemoglu, D., Moscona, J., and Robinson, J.A. (2016). “State Capacity and American Technology: Evidence from the Nineteenth Century”. *American Economic Review: Papers & Proceedings* 106(5): 61–67.

Ames, E., Rosenberg, N. (1968). “The Enfield Arsenal in Theory and History”. *The Economic Journal*, 78(312), 827-842.

Broadberry, S.N., Irwin, D.A. (2004) “Labor productivity in the United States and United Kingdom During the Nineteenth Century, National Bureau of Economic Research (NBER), NBER Working Paper 10364 (http://www.nber.org/papers/w10364, accessed July 30, 2022).

Cesari, G.S. (1970) *American Arms-Making Machine Tool Development, 1798-1855*, unpublished PhD thesis, University of Pennsylvania.

Chandler, A.D. Jr. (1977) *The Visible Hand: the managerial revolution in American business*, Cambridge, MA: Harvard University Press.

Coad, J. (2005). *The Portsmouth Block Mills: Bentham, Brunel and the start of the Royal Navy’s Industrial Revolution*. Swindon, UK: Rachel Howard, Publishing.

David, P. *Technical Choice, Innovation and Economic Growth: Essays on American and British Experience in the Nineteenth Century* (1975), Cambridge, UK: Cambridge University Press.

David, P. (2004) “The Tale of Two Traverses: Innovation and Accumulation in the First Two Centuries of U.S. Economic Growth”, Stanford Institute for Economic Policy Research (SIEPR), SIEPR Discussion Paper No. 03-24 (https://econwpa.ub.uni-muenchen.de/econ-wp/mac/papers/0502/0502019.pdf, accessed July 30, 2022).

David, P., Abramovitz, M. (2001). “Two Centuries of American Macroeconomic Growth: From Exploitation of Resource Abundance to Knowledge-Driven Development”, Stanford Institute for Economic Policy Research (SIEPR), SIEPR Discussion Paper No. 01-05.

Deyrup, F. (1948). *Arms Makers of the Connecticut Valley: A Regional Study of the Economic development of the Small Arms Industry, 1798-1870*. Smith College Studies in History, Vol. 33, Northampton, MA: Smith College.

Engerman, S.L., Sokoloff, K. (2000). “Technology and Industrialization, 1790-1914”, in S.L. Engerman, S.L. and R.E. Gallman (eds.), *Cambridge Economic History of the United States: The Long Nineteenth Century*, pp. 367-402, Cambridge, UK: Cambridge University Press.

Ferguson, E. S. (1962). “On the origin and development of American mechanical “Know-How”. Mid-America Studies Association, 3(2), 2–16.

Field, A.J. (1985). On the unimportance of machinery. *Explorations in Economic History* 22(3): 378-401.

Floud, R.C. (1974) “The Adolescence of American Engineering Competition, 1860-1900”, *The Economic History Review*, 27(1), 57-71.

Habakkuk, H.J. (1962) *American and British Technology in the 19th Century*, Cambridge, UK: The University Press.

Hirschhorn, L. (1986) *Beyond Mechanization: Work and Technology in a Post-Industrial Age*, Cambridge, MA: The MIT Press.

Hounshell, D. (1984) *From the American System to Mass Production, 1800-1932*, Johns Hopkins University Press.

McNeil, I. (1996) *An Encyclopedia of the History of Technology*, London: Routledge.

Irwin, D. (2000) “How Did the United States become a netexporter of nanufactured goods”. National Bureau of Economic Research (NBER), NBER Working Paper No. 7638 (http://www.nber.org/papers/w7638, accessed July 30, 2022), Cambridge, MA.

Landes, D.S. (1999) *The Wealth and Poverty of Nations: Why Some Are So Rich and Some So Poor*. New York: W. W. Norton & Company.

Lebergott, S. (1966). Labor Force and Employment, 1800—1960. In *Output, Employment, and Productivity in the United States after 1800*, pp. 117-204. National Bureau of Economic Research (NBER), Cambridge, MA (http://www.nber.org/books/brad66-1, accessed July 30, 2022).

Lindert, P.H., Williamson, J.G. (2016) *Unequal gains: American growth and inequality since 1700*. Princeton: Princeton University Press.

Marx, K. (1887). *Capital: A Critique of Political Economy, Volume 1*. Progress Publishers, Moscow (https://www.marxists.org/archive/marx/works/1867-c1/, , accessed July 30, 2022).

Medeiros, C.A. (2004). “O Desenvolvimento Tecnológico americano no pós-guerra como um empreendimento militar”, in J.L. Fiori (ed.), *O Poder Americano*, pp. 139-178, Petrópolis, BR: Editora Vozes.

Milward, A.S., Saul, S.B. (1979). *The Economic Development of Continental Europe: 1780–1870*. London: George Allen & Unwin.

Page, A. (2015). *Britain and the Seventy Years War, 1744-1815: Enlightenment, Revolution and Empire*. London: Palgrave.

Pope, C. (2000) “Inequality in the Nineteenth Century”, in Engerman, S.L., Gallman, R.E., (eds.), *Cambridge Economic History of the United States: The Long Nineteenth Century*, pp. 109-142, Cambridge, UK: Cambridge University Press.

Ricardo, D. ([1817] 1951). On the Principles of Political Economy and Taxation. In P. Sraffa and M. Dobb (eds.), *The Works and Correspondence of David Ricardo: Volume 1*, Cambridge, UK: Cambridge University Press

Roe, J. W. (1916). *English and American Tool Builders*. New Haven, CT: Yale University Press.

Roise, J., Waldenstrom, D. (2014). Long-Run Trends in the Distribution of Income and Wealth. Institute for the Study of Labor (IZA), IZA Discussion Paper 8157 (https://docs.iza.org/dp8157.pdf, accessed July 30, 2022).

Rothbarth, E. "Causes of the Superior Efficiency of U.S.A. Industry as Compared

with British Industry", *Economic Journal*, 56(223), 383-90.

Rosenberg, N. (1963) "Technological Change in the Machine Tool Industry”, *Journal of Economic History*, 23 (4), 414-443.

Rosenberg, N. (1977) “American Technology: Imported or Indigenous”, *The American Economic Review*, 67(1), 21-26.

Rosenbloom, D. (1993) “Anglo-American Differences in Small Arms Manufacturing”, *Journal of Interdisciplinary History*, 23(4), 683-698.

Saul, S.B. (1967) "The Market and the Development of the Mechanical Engineering Industries in Britain, 1860-1914", *The Economic History Review*, 20(1), 111-130.

Smith, M.R. (1987) *Military Enterprise and Technological Change: Perspectives on the American Experience*, Cambridge, MA: The MIT Press.

Temin, P. (1966) "Labor Scarcity and the Problem of American Industrial Efficiency in the 1850s", *Journal of Economic History*, 26(3), 277-298.

United States Bureau of the Census [U.S. Census] (1865). *Manufactures of the United States in 1860*. Washington: Government Printing Office (https://www2.census.gov/library/publications/decennial/1860/manufactures/1860c-01.pdf, accessed July 30, 2022).