Technological Advance and the "Military-Industrial Complex" in Early America

Nicholas Miller Trebat*

Abstract: This essay discusses the rise of the "American System of Manufacturing", a term referring to manufacturing techniques using specialized machine tools which dramatically reduced labor requirements in the 19th century and allowed for the production of large quantities of standardized goods. This "System" is widely regarded as the conceptual and technological predecessor of mass production technology, based on the mass production of machine-produced interchangeable parts. Neoclassical theory, we argue, can account for neither the emergence nor the diffusion of the American System. We point to substantial evidence showing the US War Department was the key agent in stimulating the basic innovations and spreading knowledge about mass production technology throughout the American manufacturing sector.

Resumo: Este trabalho discute a emergência do "Sistema Americano de Manufaturas", um termo que se refere ao uso de máquinas-ferramentas especializadas e outras técnicas que reduziram dramaticamente as necessidades de mão-de-obra no século 19 e permitiram a produção de grandes quantidades de produtos padronizados. Este "Sistema" é amplamente reconhecido como o precursor conceitual e tecnológico da tecnologia de produção em massa, baseada na produção mecanizada de partes intercambiáveis. Este ensaio argumenta que a teoria neoclássica é incapaz de explicar tanto a emergência quanto à difusão do "sistema Americano", e aponta para evidência substancial demonstrando que o Departamento de Guerra foi o agente chave no patrocínio das inovações básicas e na difusão de conhecimento sobre a tecnologia de produção em massa ao setor manufatureiro como um todo.

Sessões Ordinárias
Área 7: **Trabalho, Indústria e Tecnologia**
Sub-área 7.2: **Economia Industrial, serviços, tecnologia e inovações**

* Professor Temporário, Instituto de Economia, Universidade Federal do Rio de Janeiro (IE-UFRJ).

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1. Introduction

Though surpassing the British economy in size only in the early 1870's, and in per capita income around 1905[†], US labor productivity in manufacturing exceeded the British level as early as 1840. Broadberry and Irwin (2004) estimate that throughout the period 1840—1900, American manufacturing workers were roughly twice as productive as their English counterparts. Economists generally attribute the efficiency of 19^{th} century American manufacturing to the emergence of the "American System of manufactures", a term coined by British visitors to the United States in the 1850s and referring to manufacturing techniques using special-purpose machine tools and other equipment which dramatically reduced labor requirements and allowed for the production of large quantities of standardized goods. The "System" is widely regarded as the conceptual and technological predecessor of mass production technology, based on the mass production of machine-produced interchangeable parts.

Rosenberg (1977) observes that the study of technical change in 19^{th} 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, and involving the use of highly-specialized machinery, a system so different from anything known in Europe that, by mid-century, it was widely referred to there as 'The American System of Manufacturing'".

We will argue in this essay that the widely-accepted neoclassical approach to the American System—emphasizing unique aspects of American factor endowments and consumer demand—can explain neither the emergence nor diffusion of the basic machines and techniques of mass production. We point to substantial evidence indicating that, rather than a response to "general" macroeconomic conditions favoring the use of capital-intensive techniques, the American System was the result of a State-directed effort to alter production techniques in a single manufacturing industry—firearms. After decades of refining and improvement of mass production techniques through military sponsorship, markets in America grew sufficiently large to enable consumer durable producers to adopt the methods of "armory practice" more fully.

[†] Data provided by Angus Maddison and available at the website www.ggdc.net/maddison.

2. Neoclassical Theory and the American System

In his classic study of British and American technology, Habakkuk (1962) noted that a "large part of American industrial progress in the 19th century was due to the rapidity of technical advance in machine tools." British and French engineers had invented the prototypes for most modern general-purpose machine tools between 1775 and 1850 (such as engine lathes and steam hammers), but Americans developed "the most important new machine tools" used in precision manufacture.

The American inventions, known as automatic and special-purpose machine tools, were lighter, faster, more precise and less dependent on skilled labor than the European machines. The enhanced precision was a result of the limitations imposed on them, "limitations" in the sense that, like a computer, they were built to follow a narrow set of "instructions", such as boring gun barrels of a certain diameter. These machine tools, combined with new organizational procedures and the development of equipment (such as fixtures and gauges)to measure the precision of machine cuts and conformity of parts to uniform specifications, would by the mid-1850s form the core of the American System.

The emergence of the "American System" in the mid-19th century raises three basic questions for historians of American economic history: how did the innovations associated with mass production technology come about, why were they invented in the US (as opposed to, say Britain), and how were they diffused throughout the manufacturing sector?

Neoclassical economists argue the rise of the American System is attributable to unique aspects of American factor endowments and consumer demand. With regard to demand, the argument is simple: larger markets and greater income equality in America implied a greater homogeneity of consumer preferences. This created incentives for capitalists to produce large quantities of standardized goods. Mass production of standardized goods, in turn, favored mechanized productive processes and stimulated the search for machine innovations. Out of this search arose the machines and techniques of the American System.

Regarding factor endowments, the arguments can be divided in two basic categories: the "more machines" and the "better machines" theories (Temin, 1966). The former, pioneered by Rothbarth (1949) and Habakkuk (1962), is that "labor scarcity" (higher wages) in the US and an abundance of land and natural resources provided a favorable environment for labor-saving innovations. Labor is assumed “scarce” in America because of the greater availability of land, i.e. manufacturing wages had to be set at high levels to induce workers to leave their farms and work in factories. Capitalists in America thus had greater incentives to substitute machines for high-cost labor (hence “more machines”), and these greater incentives helps explains why America, and not Britain, developed mass production techniques.

The “better machines” hypothesis is essentially a more sophisticated version of the “more machines” argument. This hypothesis also originated with Habakkuk (1962), but it is usually associated with David (1975, 2004) and Rosenberg (1977). These authors claims labor scarcity and natural resource abundance led to the development of a “better” technology in the US, that is, American manufacturers required less capital and less labor than British firms to produce a given unit of output. Figure 1 illustrates this point. Q_{US} and Q_{GB} are isoquants reflecting the quantities of “capital” and labor required to produce one unit of a given commodity in America and Britain, respectively. Q_{US} is closer to the origin than Q_{GB}, reflecting the “better technology” hyptothesis.

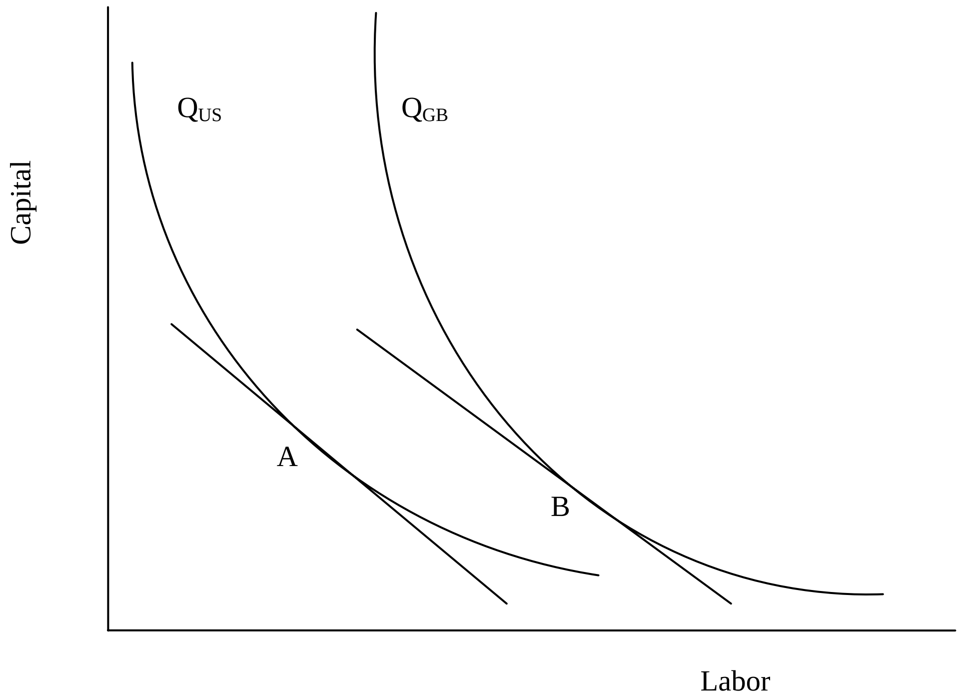
David (1975) argues that even if factor price ratios (the ratio of the wage rate to the profit rate, the latter considered the “price of capital”) had been the same in America and Britain (the factor price ratios A and B are parallel in Figure 1), “learning” effects and the “capital- and resource-using bias” of technical change in America created incentives for manufacturers to use more capital-intensive and resource-intensive techniques than British manufacturers. “Thus”, David (1975) suggests, “even if the same labor-capital price ratio…had faced producers in Britain and America, the comparatively greater availability of natural resources would have suggested to some American producers the design, and to others the selection for use, of more capital-intensive methods” (p. 89-90)

This point warrants closer analysis. David and Rosenberg assume technical progress in the 19th century had a “capital-and resource-using bias” reflecting the backwardness of scientific knowledge in this period. The technical knowledge required to use natural resources more efficiently, they argued, was only developed with innovations in electrical engineering and chemistry towards the end of the 19th century. Thus, for innovation to take place in the 19th century, it generally had to take the form of machine inventions that were very wasteful of natural resources. American producers were uniquely able to exploit this situation because they had two strong incentives to use machines: expensive skilled labor and abundance of cheap resources such as wood. Britain, to the contrary, had few natural resources and cheap labor, making it more profitable for British manufacturers to use labor-intensive methods. As a result, British manufacturers did not gain as much experience ("learning by doing") with capital- and resource-intensive techniques, and thus they were not able to take advantage of what 19th century technical change, constrained by the state of scientific knowledge, had to offer.

Since Americans chose to use more capital-intensive techniques early in the 19th century, Rosenberg (1977) and David (2004) argue, American manufacturing embarked on a path-dependent course in which greater experience with machine-intensive techniques led to rapid improvements in labor-saving technology and an even greater bias toward the use of capital-intensive techniques. These improvements led to the shifting in America's production isoquant (Q_{US}) relative to Britain, shown in Figure 1. The machines of interchangeable parts manufacture emerged out of this process.

Rosenberg (1977) offers the clearest example of this reasoning: "In numerous ways", writes the author, "resource abundance and labor scarcity, and the nature of industrial technology, thrust the American economy very quickly toward the capital-and resource-intensive end of the spectrum of techniques", and this "initial shift to the capital-using end of the spectrum" generated a "learning" process leading to "new patterns of specialization and division of labor among firms…as a result of which the American economy developed a degree of technological dynamism and creativity" superior to that of the Europeans" (p. 24-5).

Figure 1



The neoclassical approach is widely-accepted. David and Abramovitz (2001) offer a synthesis of the "supply" and "demand" explanations for the rise of mass production technology by arguing that, in addition to the "learning effects" born of greater capital- and resource-intensity (p. 148-9).,

> The American development of mass production methods was also encouraged by the country's higher and more widely diffused incomes,which supported an ample domestic market for the new metals-based [standardized] durable goods. By contrast, Europe's lower and less equally distributed incomes initially restricted the market for such goods to its well-to-do classes…and thereby delayed the full application of American mass production methods.

In their discussion of American industrialization between 1790 and 1914, Engerman and Sokoloff (2000) argue: "[T]he nature of American factor proportions and technology, due to a relatively greater abundance of available land and a scarcity of labor, meant more capital and land-intensity in American manufactures as well as…a greater search for labor-saving innovations in the United States than in Britain…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" (p. 378)

Harley (2003) claims the "'American system of manufacturing' developed under" conditions of high real wages and "modest class differences", which "created a mass market for standardized manufactured goods". These conditions reinforced the effects of relative factor endowments on American firms as they "adopted mechanized production because machine techniques, although they used expensive capital and were wasteful of (cheap) raw materials and energy, economized on expensive skilled labour". Europeans, the author adds, "did not find it profitable to follow the American lead. Raw materials were more expensive, skilled labour was cheaper, and mass markets for standardized products were less developed."

Landes (1999, p. 301) offers another example:

> The decisive and most distinctive American innovation, though, was not any particular device…but a mode of production—what came to be called the American system of manufactures. This was a creative response to 1) a market free of the local and regional preferences and the class and status distinctions that prevailed in Europe, hence ready to accept standardized articles; and 2) the scarcity of labor relative to materials. The two were related. In a labor scarce economy, standardization was a way of dividing, hence of simplifying, tasks and making them repetitive, thus substantially enhancing productivity.

3. Problems with the Neoclassical Approach

Neoclassical theories of 19th century technical change in America cannot come to terms with several key facts. First, while it is well-known that the basic innovations in American machine tools took place before 1850, there is no evidence suggesting British manufacturing firms were less capital-intensive than American ones before 1880. In fact, there is strong evidence (Field, 1983, 1985) that the British economy had a higher overall capital-labor ratio throughout most of the 19th century, a result that holds even if we restrict the definition of "capital" to mean machines or machinery services. "British capital-labor ratios", Field observes, "were not lower than the corresponding American ratios in 1860. They were higher. Even with respect to manufacturing machinery considered alone, it appears that in 1860 Britain used more machinery services per unit of manufacturing output and per unit of manufacturing labor than did the United States."

According to Field (1985), the myth concerning greater American capital-intensity derives from an erroneous interpretation of British investigations of US manufacturing in the mid-1850s. In 1854, the British Parliament sent a group of observers to the US to study arms production and a few other manufacturing sectors in this country. Based on the inspectors' accounts, the British Board of Ordnance published a report in 1855 referring to an "American System of manufactures" (this is the origin of the term) characterized by intense division of labor and automatic, sequentially-operated machines. Fields explains that the "British observers, whose reports lie at the origin of this longstanding debate, focused on the characteristics and operating procedures of machinery in a small number of manufacturing industries….The incorrect belief in the greater capital intensity of the American economy has resulted, in my judgement, from misunderstandings of the significance of what the British observers reported…"

Indeed, the British inspectors affirmed that most British machinery was superior to that found in the US, but that Americans used interesting specialized machine tools not found in England with universal applications in industry. As the *Report from the Select Committee on Small Arms* noted, American machinery "usually employed by engineers and machine-makers…are whole behind those of England", but "in the adaptation of special apparatus to a single operation in almost all branches of industry the Americans display an amount of ingenuity, combined with undaunted energy, which as a nation we should do well to imitate."

Field's results severely weaken both the "more" and "better" machine approaches. Both, recall, assume American manufacturing was more capital-intensive than in Britain. In the case of "more machines", the dependence on a greater capital-labor ratio in the United States is obvious: the supposedly higher American ratio reflected greater incentives to substitute capital for labor in America, and these incentives are what led to machine innovations. If British capital-labor ratios were indeed not lower, then obviously such "greater incentives" did not exist, and the theory falls apart.

Similarly, "better machines" theory claims greater abundance of natural resources in America allowed manufacturers to adopt more capital-intensive techniques. Britain, less well-endowed, opted for labor-intensive or "craft" methods, and thus did not "learn" as much as the more intensely "capital-using" Americans. If, however, the British used techniques of greater or even merely the same capital-intensity, then clearly neither labor scarcity nor natural resource constraints impeded British manufacturers from using machines to the extent David and Rosenberg claim. Thus, the question inevitably emerges: if Britain used as many machines per unit of labor than America, then how can experience and "learning" explain the rise of a unique and "better technology" in the United States? British producers should have had just as many, if not more, opportunities to "learn" with the use of machine-intensive production processes.

One could perhaps argue that British machines were simply "worse" than American machines because 19th century machines innovation had a "resource-intensive" character. That is, one could concede that British manufacturing was not less capital-intensive, but affirm, following David's suggestion (who in turn had borrowed it from Habakkuk), that the revolutionary machines of the 19th century were of necessity wasteful of natural resources, giving the Americans a decisive advantage. One problem with this argument is that, in the absence of deeper scientific or economic explanations as to why it would be true, one can easily construe other arguments affirming precisely the opposite, i.e. that natural resource *scarcity* creates incentives for the invention of "better", more efficient machines. The key improvements made to the steam engine in the late 18th century, for example, were extremely resource-saving (on the use of coal) and also allowed factories to be sited far away from rivers. Why were such innovations suddenly no longer possible in the 19th century? If resource-saving inventions required advances in chemistry and engineering occurring only in the late 19th century, why were these constraints on innovation not operative in the late 18th century, when several major resource-saving innovations were introduced?

Rosenberg (1977) himself notes abundant natural resources were at times a constraint on American technological development. Britain's rise to dominance in iron production in the 18th century was in large part a response to inadequate timber supplies, which forced producers to develop more efficient processes using coal. Britain remained the dominant producer throughout the 19th century, while American producers, relying on abundant wood resources, ignored Britain's more advanced technology. New England's abundant water power supply also delayed America's adoption of the more advanced stationary steam engine, widely-used in Britain factories.

No evidence supports the "better machines" claim that American machinery or "technology" was in a general sense superior to that in Britain. Indeed, as noted above, the British inspectors believed that American machines were mostly inferior. Temin (1966) also pointed to many historical references to American equipment as less durable or "flimsier" than British machines. Though none question American superiority in special-purpose machine tools in America, many British industries, such as iron, barrel-welding, textile machinery and heavy machine tools, were much more advanced than in the US. Saul (1967) observed that in the latter half of the 19th century British textile machinery and ship engines were more advanced and produced with more concern for standardization than American versions.

Floud (1974) makes the interesting point that, though there is no question of American superiority in special-purpose tools, there is also no evidence that American machinery was more productive or even competitive on the world market with British machinery. American machinery exports, the author notes, grew very slowly from 1850 to 1890, while British machinery dominated the world market. This was the case despite low British and French tariffs on imported machinery throughout the second half of the 19th century, far lower, of course, than the prohibitive American tariffs. Thus, though manufacturing labor productivity was very high since at least 1840, there is no indication that overall unit costs of American production was lower than in other advanced countries before 1890.

In the 1890s, there was a boom of American machinery exports, from which point on the Americans and the British controlled roughly equal shares of the world market until 1913. This period, Floud concludes, represents the coming of age of American manufacturing. Before this, however, it seems machinery was essentially a highly protected domestic industry in the US, American superiority being limited to a small number of "ingenious" machines.

With regard to consumer demand, as noted most of the basic machines and techniques of the American System were invented by 1850, more than two decades before American GDP surpassed that of Britain and several years before America surpassed Britain even in population size. In short, mass markets did not exist in pre-Civil War America, and thus these cannot be inferred as an explanation of innovations predating their appearance.

Further, there is little evidence that America was dramatically more egalitarian than Britain in the first-half of the 19th century. America was never, as Landes (1999) suggests, a society free of "class and status" distinctions prevalent in Europe. Alice Hansen Jones[‡] noted wealth and income distribution had been highly skewed since the colonial era, and inequality likely increased throughout the 19th century. Pope (2000) estimates a Gini coefficient of 0.83 for financial and real estate wealth among property-holders in America in 1870, roughly equal to the Gini coefficient for net worth in the US in 2007 (Wolff, 2010). American society, at least throughout most of the 19th century, was not much more egalitarian than it is today.

The America as socialist utopia myth is not valid even in relative terms. Lindert estimates 10% of the American population controlled 70% of total wealth in 1800, compared to 84% in Great Britain (cited in Pope, 2000, p. 135). Soltow (1984, 1992) suggests the discrepancy in income

[‡] *American Colonial Wealth*, Ayer Company, 1977

and wealth distribution in the US and England was smaller and changed little throughout the 19th century.

4. Military Sponsorship of Interchangeable Manufacture

The most obvious indication that "general" macroeconomic conditions, such as factor endowments or consumer demand, did not lead to the emergence of the American System is the high level of concentration of American machine tool innovations in a small number of industries; indeed, in a single industry—firearms. On the role of American arms producers in the development of mass production technology, Roe (1916) affirmed in his classic study: "In sketching the development of interchangeable methods in American shops, we have confined our attention to gun makers chiefly. 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" (p. 144). Roe (1916) added that machine tool technology for interchangeable manufacture developed very rapidly. In 1775, Roe noted, methods for cutting wood and metal remained essentially medieval, yet by 1850 "it was substantially that of today. In fact, most of this change came in one generation, from about 1800 to 1840."

Though a complete survey is beyond our limits, extensive research (Smith, 1977, 1987; Hounshell, 1984) shows that the War Department, precursor to today's Department of Defense, introduced the concept of interchangeability in American manufacturing and heavily subsidized the development of mass production techniques. New England textiles were the first major industry in America, but they had a minor role in the development of machine tools. The first specialized machine tool producers in the US were subsidiaries of large textile firms, but the lathes and planers built by these companies did not provide the precision and speed needed to produce interchangeable parts. These depended on the invention of special-purpose machine tool such as turret lathes, milling machines and grinders, the three most basic tools of modern industrial processes.

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 US War Department developed several policies fundamental to the development of the American System, the most important of which was the construction of the federal arms factories at Springfield, Massachusetts in 1794 and at Harper's Ferry, Virginia in 1798. The federal arsenals became the country’s largest arms producers and symbols of manufacturing excellence until at least 1860. Also in this period the War Department began anticipating payments to private arms factories. Deyrup (1970) argues these cash advances created the American arms industry: “[T]he contract system was of immense value both to the government and the contractor, for aside from bringing the [arms] industry into existence it promoted a spirit of cooperation and mutual aid unique among early American manufacturers, which had much to do with the rapid development of the industry in the first thirty years of the nineteenth century”.

In 1798, the War Department ordered 10,000 interchangeable muskets from the private factories of Simeon North and Eli Whitney. This demand for interchangeability, that went unmet given the still primitive methods, reflected the influence of French military officers who served as advisers to American officers during the war of independence (1776-1783). French military arsenals had adopted the concept of interchangeability or “uniformity” in the 1760s. Between 1794 and 1815, the Springfield Armory instituted a more intense division of labor and introduced precision instruments to measure the conformity of its firearms with fixed specifications. Hounshell argues these changes transformed armsmaking “from a craft-pursuit into an industrial discipline and the weapon from a shop product into a factory product”. Chandler (1977) agreed, observing that before 1825 the Springfield arsenal had become “an even more important prototype of the modern factory than the integrated textile mill”, and its “accounting and inspection controls...set up at the Springfield Armory were certainly the most sophisticated used in any American industrial establishment before the 1840s” (p. 73-5).

Machine tool progress accelerated in the arms industry after 1812. In 1813, the War Department awarded arms manufacturer Simeon North a huge contract for 20,000 pistols with component parts “so exactly alike”, ordered the Department, “that any limb or part of one pistol may be fitted to any other pistol of the 20,000” (Hounshell, p. 28).

Battison (1973) and Smith (1973) showed that it was North who, attempting to fulfill this contract, invented the milling machine, the first major innovation of the American System. After visiting North’s factory in 1816, Springfield and Harper’s Ferry (the federal armory in Virginia) officials introduced the milling machine at the arsenals. Smith (1987) observes that the Ordnance Department “had an 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” (p. 78).

Armsmakers such as North, dependent on government contracts, had to comply. As a result, very few of the basic machines and processes of interchangeable manufacture received US government patents before the Civil War. “Such an ‘open door’ policy”, Smith (1987) notes, “while accentuating the public-service orientation of the Ordnance Department, explains why so few crucial machines and machine processes were actually patented during the antebellum period” (p. 78).

The next major innovation sponsored by the Ordnance Department was the “Blanchard lathe”, a machine tool composed of 14 component machines to produce gunstocks. Gunstocking machinery, of which the Blanchard lathe was the key component, was the aspect of American woodworking that most impressed the British observers in the 1850s, considered “so spectacular that it was the only machinery that that the [British] Committee…ordered without comparing alternate uses for their funds” (Temin, 1966, p. 282).

Derived from French and British machines used to produce wooden blocks for warships, the Blanchard lathe “set American manufacturing firmly on the road toward mechanized production” (Hounshell, p. 35). The key to Blanchard’s device was the cam, a rotating piece serving as the control element of the lathe and, in Hirschhorn’s (1988) words, a “fundamental building block” of mechanization.

The Blanchard lathe revolutionized the production of durable goods such as shoes, chairs, tables, ax handles and wagon wheels. The basic principles guiding the innovation were used in the construction of automatic lathes in the 1850s, which not only improved industrial productivity but made it possible for goods such as sewing machines, typewriters, bicycles and, eventually, automobiles to be built.

The history of the Blanchard lathe’s invention is typical of machine tool progress in America. In 1818, Thomas Blanchard invented a primitive version of the “Blanchard lathe” while building musket barrels for the Harper’s Ferry arsenal. Blanchard was soon hired as an inside contractor at Springfield, where he perfected his lathe using the arsenal’s raw materials, machines and power supply. The final version was complete by around 1825.

Blanchard’s sequentially-operating machine practically eliminated hand labor in the making of gunstocks: “It is this sequential operation of special-purpose machines which characterized mechanization in American manufacturing” (Hounsehell, p. 35). As was the case with North’s milling machine, Blanchard's lathe set in motion a period of rapid progress in special-purpose machine tools.

The federal arsenals were also crucial in subsidizing the innovations of John Hall, an inside contractor at Harper's Ferry who worked extensively with North and mechanics at the Springfield arsenal. Hall improved North's milling machine and invented precision instruments and other techniques for standardizing production. Hall's machines were more durable and stable than North's (hence more precise), and were, according to Smith (1973, p. 581), very similar to mid-20th century versions. Hall's machines, like Blanchard's, could be operated with very little human skill or effort. As was the case with production at Springfield, the unit costs of Hall's production remained high because the fixed costs of the various machines and gauges used were expensive. Hall's innovations, however, opened the way for future productivity gains.

Hounshell notes that Hall's work with gauges and precision techniques (such as the use of "bearing points" to avoid the compounding of mistakes in sequential machining operations) became "fundamental principles" of mechanized manufacture. Discussing applications of Hall's techniques to the operation of the Blanchard lathe at Springfield in the 1850s, Cesari (1970) added: "The principles upon which the entire process was based and for which the battery of machines was specifically designed were valid over a century later in all machine processes seeking similar results, whether in wood or metal".

Hall's main contribution to the American System was to unite the concepts of mechanization and interchangeability. Until the 1850s, much of the scientific and industrial community doubted whether interchangeability was possible, and many experts denied that machines would ever be capable of producing interchangeable parts. Hall showed interchangeability might not only possible but that mechanization was the key to turning the 18th century French concept of "uniformity" into a reality.

The 1830s and 1840s represented transitional stages in the development of interchangeable manufacture, and here the federal arsenals again played a crucial role. By the mid-1830s, the American Northeast had become a sophisticated manufacturing complex, much of it located in the vicinity of the Springfield Armory. The proliferation of "armory practice", as Hounshell calls the American system of arms production, was a result of the Ordnance Department's above-mentioned "open door" policy. The federal arsenals facilitated the diffusion of North, Blanchard and Hall's innovations to other industries. They did so by adopting an explicit policy of knowledge-sharing: military officers visited the factories of their suppliers and opened arsenal doors to visits, encouraging inventors and firms of any kind to take notes and draw designs of the materials, machines and equipment in use (Smith, 1987, p. 54).

An example from the watch industry illustrates the importance of the federal arsenals as training centers and symbols of manufacturing excellence. American watch innovator and entrepreneur Aaron Dennison looked to “armory practice” in the 1840s as inspiration for what was to become the well-known Waltham Watch Company in the 1850s. Dennison predicted in 1840 that within two decades watch manufacturing in the US would be “reduced to a system as perfect and expeditious as the manufacture of firearms at the Springfield Armory” (cited in Church, 1975, p. 621). In what had become a typical practice among manufacturers, Dennison hired a mechanic from the Springfield arsenal in 1850 to help oversee the application of the arsenal’s “factory methods” to watch manufacturing.

Though not seeking to attain the arsenals’ degree of interchangeability, shoemakers, watchmakers and woodworking establishments adopted the machines and some of the techniques used at the arsenals and other large gun factories. As suggested above, the arsenals also functioned as public training centers: in addition to copying technology in use at the arsenals, many important manufacturers such as Ames Manufacturing Company, Brown and Sharpe, Providence Tool, the Colt Armory, and George S. Lincoln and Company, frequently hired former arsenal employees.

In the 1840s, Lincoln and Company began to sell its very successful milling machine called t he Lincoln miller. According to Woodbury (1960), the prototype for the Lincoln miller was built by Frederick Howe of the Robbins and Lawrence Company, a firearms and machine tool company from Vermont. Howe had designed machines for North’s factory, and based the Lincoln miller prototype on a model used at the Springfield arsenal (McNeil, 1990, p. 408).

Rosenberg (1963) also discusses Springfield’s role in the development of the milling machine, emphasizing the work of the arsenal’s master-armorer Thomas Warner,: “[The milling machine’s] subsequent development was largely the work of the national armories, especially the highly important work of Thomas Warner at the Springfield Armory, and such gun-producing firms as Robbins and Lawrence...” (1963, p. 428). Milling techniques, Rosenberg notes, basically stabilized after the Lincoln miller began to be sold commercially to arms producers, sewing machine companies and other manufacturers in 1855 (p. 428).

5. The Role of Military Demand

The War Department was an important source of demand for “transitional” companies such as Ames Manufacturing. Company archives from the 1850s reveal Ames was Springfield’s exclusive supplier of gunstock machinery, based, of course, on the Blanchard lathe, developed at the Springfield Armory’s own expense decades earlier.

The turret lathe, a descendent of Blanchard’s machine invented by Stephen Fitch in 1845, is one of the best examples of military expenditures stimulating machine tool development. Fitch built the machine while fulfilling a contract to produce 30,000 gunlocks for the US Army. The turret lathe eliminated the need for human labor to adjust the position of parts during sequential cutting operations, revolutionizing manufacturing processes dependent on large quantities of small parts, such as screws. On the significance of the turret lathe for American industrialization, Oliver (1956) explains: “From this instrument emanated the long series of automatic tools that have characterized American industry and have made possible the technique of mass production” (p. 273).

The turret lathe “was so time-saving that it was rapidly taken up by other manufacturers after 1850” (McNeil, p. 410). A mechanic at the Colt Armory (a private factory run by Samuel Colt) introduced the double-turret lathe in 1852, and Jones and Lamson, formerly Robbins and Lawrence, began selling the machine commercially in 1858. “From this point on”, notes Rosenberg (1963), “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” (p. 429).

Illustrating that the American System did not emerge as the optimal response of profit-maximizing agents, unit costs of production at the arsenals and private gun factories were very high before 1860. Though many authors emphasize high labor costs in America, few recall that the machines used by antebellum gunsmiths were also very expensive, prohibitively so for smaller producers without federal contracts. In fact, there is no record in this period of sophisticated, American System equipment being used by arms producers supplying for the private market alone (Rosenboom, 1993).

Though incomplete, data from government census reports suggest that Springfield and Harper’s Ferry, producing exclusively for the federal government, accounted for more than one-third of small arms production in the US. These two arsenals produced 23,000 firearms in 1840, while six or seven large private factories produced between 1,000 and 8,000 each. The vast majority of producers, roughly 95%, produced less than 500 firearms per year and had less than 20 employees. It is unlikely that the smaller gunsmiths, producing for local militias and civilians, had the incentive or capacity to invest in the machines and equipment needed to comply with War Department specifications.

US census reports identify six of the eight private factories producing more than 1,000 firearms in 1840. Of these six, four (Simeon North, Robert Johnson, Nathan Starr and Asa Waters—whom Blanchard was working for in 1818 when he invented a primitive version of his lathe) had federal contracts. The two large companies that do not appear to have had federal contracts in 1840, Kendall and Company of Vermont and Samuel Colt's Patent Arms Manufacturing Company, went out of business in 1842. Satterlee and Gluckman (1940) noted that Colt's company went bankrupt due to "lack of public and government support".

This impression is reinforced by the way in which Colt re-entered the arms business in 1847, after he was awarded an Army contract for 1,000 pistols. The reasons for Kendall and Company's bankruptcy are obscure, but, similar to Colt, the company resurfaced in 1845 after winning a US Army contract to supply Springfield Model 1841 rifles. Rosenbloom affirms (1993): "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".

The location of large private arms factories reinforces the conclusion that public demand, combined with the arsenals' open door technological policy, was essential to antebellum manufacturing progress. Six of the eight large private arms factories in 1840 were in New England, relatively close to the Springfield arsenal—two in Massachusetts, three in Connecticut and two in Vermont.

Based on these observations, Rosenbloom concludes: "[T]he emergence of the American system of manufacturing in the production of small arms is attributable primarily to the distinctive characteristics of American military demand, and the direct involvement of the Army Ordnance Department in developing technologies capable of meeting the standards of interchangeability that it had established."

6. Diffusion of the American System

Hounshell's research reveals the following sequence in the diffusion of mass production techniques: sometime around the 1840s and 50s, machine tool producers such as Ames, Brown and Sharpe and Remington began marketing their machines to consumer durables producers, and themselves moved into the production of sewing machines, typewriters and other goods. Remington, who produced rifle barrels for the US Army, moved into sewing machine production in 1870 and became America's first major producer of typewriters after 1873.

The sewing machine industry, though not adopting mass production techniques more fully until the early 1880s, was responsible for important machine tool innovations based on earlier special-purpose lathes and millers. Two important innovations, derived from Fitch's turret lathe, were the automatic screw machine, invented by Christopher Spencer, a former employee of Colt Armory, and the universal grinding machine, invented by Henry Leland and mechanics at Brown and Sharpe. A prime example of the manner in which the American System evolved, Leland had begun his career as a tool builder for the Springfield arsenal and later worked at the Colt Armory and Brown and Sharpe (Leland later founded the Cadillac Motor Company).

The bicycle industry took mass production techniques to the next level in the 1890s, making major improvements in machine tools and design and introducing innovations such as ball-bearings, sheet metal stamping and electric-resistance welding. By 1900, mass production techniques were capable of being profitably applied to automobile production, which depended heavily on prior developments in the sewing machines and bicycle industries and secured the role of "armory practice" in American manufacturing. As Rosenberg (1963) noted: "The transition to automobile production for the American economy after 1900 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."

Hounshell dispels the widespread assumption (see David, 2004) that the clock or agricultural implements industries invented or quickly adopted "armory practice". Techniques used in the production of agricultural machinery were still relatively backward in the 1870s. The industry's largest firm, McCormick, only adopted mass production techniques in the early 1880s, hiring a superintendent with extensive experience in the firearms and sewing machine industries. Hounshell notes that, compared to Springfield or even the sewing machine manufacturers, the

McCormick factory was “crude” technologically, employing “almost no special- or single-purpose machinery, and there is little evidence that [the owners] knew of the techniques of special gauges, jigs, and fixtures which distinguished the arms industry” (p. 7).

Interestingly, one of the best sources on the diffusion of mass production techniques is Nathan Rosenberg (1963), one of the originators of the “better machines” hypothesis discussed above. Rosenberg, when not theorizing on the influence of factor endowments on technical change, shows clearly that technological progress in America took the form of exogenous shocks in the firearms and machine tool industries which, because of certain traits common to all manufacturing processes, disseminated to other industries. A “responsive machinery-producing industry has been the key to successful industrialization” (Rosenberg, 1977). The critical role machine tools play in industrialization processes, the author explains, results from basic similarities in all manufacturing processes, such as the refining, bending and cutting of metal; because of these similarities, products such as guns and sewing machines, though apparently very different, are identical in a more abstract sense. Thus, knowledge and experience in one industrial sector can be easily transferred to other sectors.

Rosenberg calls this feature of industrialization “technological convergence”: “The machining requirements and processes of sewing machine manufacturing were broadly similar to those of firearms production” (1963, p. 431). As a result, the solution of technical problems in arms production in the 1850s had immediate applications in the sewing machine industry. Experience with sewing machine production, in turn, led to dramatic improvements in the milling machine, which were applied to firearms production and, in fact, to the production of almost any durable good.

In the absence of technological convergence, firms specialized in the production of machine tools would have remained little more than subsidiaries of arms producers or textile companies, as they had been throughout the 1820s. The large integrated mills produced within their own factories the special machines needed for their operations. As a result of technological convergence, an independent, specialized machine tool industry emerged, producing the same machines for many different industries. “Individual firms producing milling machines would not have emerged in an economy where only firearms manufacturers employed milling machines” (Rosenberg, 1963, p. 425).

The emergence of specialized machine tool producers after 1830, such as Pratt and Whitney and Robbins and Lawrence, allowed metalworking firms to stimulate technical progress in manufacturing as a whole, and the core of this technological nucleus was the machine tool industry. When new problems emerged and were solved in the latter industry, the new techniques benefitted all other industries dependent on metalworking operations.

7. Market Size and Armory Practice

Though important, Rosenberg's notion of "technological convergence" is in need of qualification, for the process of diffusion of the American System was not as rapid as Rosenberg suggests. Mass production techniques, as adopted in the arms industry, were rare in non-weapons manufacturing before 1880. Even the dominant sewing machine manufacturer, Singer, was slow in adopting armory practice, still using a "mixture" of the "American System" and "European" methods in the 1870s. "Even as late as 1881", Hounshell notes, the parts of Singer sewing machines were not interchangeable, and "some fitting and filing were required to put sewing machines together" (p. 113).

Doubtless Singer benefitted from the special-purpose machines invented by the arms industry, and the widespread use of these machines probably accounts for much of America's large manufacturing productivity over Britain by 1840. Indeed, Singer had set up a factory in Scotland in 1867 and impressed local manufacturers with the large quantity of lathes, milling and grinding machines the company used (and largely built on its own). There was a key difference, however, between the use of the special-purpose machine tools and "mass production" as adopted by gun factories. The latter implied the adoption of a laboratory-like system of production obeying bureaucratic procedures and in which large numbers of sequentially-operated machines were used in conjunction with instruments such as gauges to minimize the possibility of human error in making parts conform to specifications. This was still a very revolutionary production system in the mid-19th century and, as Hounshell illustrates, most manufacturers in America were skeptical of its benefits and unwilling to absorb its heavy fixed costs.

Hounshell demonstrates that mass production technology had not yet proven itself as the dominant, cost-competitive method of production in the 1860s and 70s. Where the machines and methods of armory practice were quickly adopted in the 1860s, such as at the Wilcox and Gibbs sewing machine company and Remington Typewriter, this was because arms and machine tool producers were in charge of production at these companies. For these firms, unlike much of the rest of American manufacturers, “armory practice” was a system they were accustomed to; the American System for them was not an expensive alternative, but the way they knew how to build machines.

Even in these cases, however, mass production technology had not yet been refined to the point where companies such as Brown and Sharpe, to whom Wilcox and Gibbs had outsourced sewing machine production, could dominate their industries. Though much more backward technologically than Brown and Sharpe, Singer dominated the market by the late-1860s using a far superior marketing strategy (Chandler, 1977). “If Singer had found highly refined armory practice to be too expensive”, Hounshell asks, “this raises the question of its economic efficiency in the context of 1870s America…if Singer was simply a technologically backward—albeit large and important—manufacturer, one must question the general diffusion of the American system of manufacturing in the post-1850s period” (p. 107).

In an early response to Habakkuk’s theory of American technical progress, Saul (1967), like Hounshell (1984), noted that neither advanced special-purpose machine tools nor the American System as a whole were widespread even in the US throughout most of the century. Economists, Saul remarked, often claim British machinery firms were heavily reliant on handicraft methods, but similar evidence exists for most US machine shops, in which, as late as 1880, “Milling machines as well as shapers were scarce, and automatic screw machines were looked upon with wonder…Turret lathes as we know them today were unknown” (p. 128).

Showing the extent to which armory practice was not yet a dominant technique in civilian industries, Singer, responding to increased demand in 1870, temporarily outsourced production to Providence Tool, a weapons and machine tool company. Singer terminated the contract in 1873, mainly because Singer’s mechanics considered Providence Tool’s techniques “sloppy” and believed some hand labor, such as filing before assembly, was necessary to produce a higher quality machine.

Interestingly, Singer and McCormick’s products were not cheaply-made or low-priced. The major sewing machine, agricultural implements and bicycle manufacturers of the late 19^{th} century, Hounshell notes, did not adopt the Fordist strategy of flooding the market with cheap, standardized products. Instead, they used marketing techniques to attract buyers. “Singer, McCormick, Pope, and the Western Wheel Works all held one characteristic in common.

Although they sold the most expensive products in their respective industries, they were the dominant firms. This fact raises serious questions about the widely-held notion that American-made products succeeded in the market because they were cheaply made and low-priced" (Hounshell, p. 9). This, needless to say, is radically at odds with the neoclassical suggestion that mass production techniques were generally adopted in American industry and were a response to "natural" macroeconomic conditions operating on all manufacturing sectors.

Hounshell argues that market size, rather than resource abundance, was the crucial factor in convincing civilian manufacturers to adopt "armory practice". This observation is to be distinguished from the neoclassical argument regarding the impact of the mass market on the American System: Hounshell, contrary the neoclassical authors, does not argue mass markets led to the basic innovations of mass production. Rather, he shows that mass markets, once they arose in the US in the 1870s, provided an incentive for civilian producers of consumer goods to finally adopt the mass production techniques developed at War Department expense decades earlier.

Durable goods producers like Singer and McCormick adopted mass production methods only when labor-intensive methods proved unable to handle consumer demand and the geographical range of their distribution networks, which forced these companies to separate production and assembly units and standardize their production across different production locations. In Singer's case the definitive step toward armory practice was taken in the late 1870s. It is no coincidence that this is precisely the period in which America surpassed Britain in terms of GDP and emerged as the world's largest and first mass market economy.

8. Reflections on Britain's Failure to Adopt the American System

As discussed in Section 2, neoclassical theory suggests Britain failed to adopt the American System because resource constraints made its techniques unprofitable, inducing British producers to retain craft methods. A more plausible answer, based on the observations made up to this point, would seem to be that the British failed to adopt the American System for the same reason most Americans did: its fixed costs were simply too high, and British market size had not yet reached the point where it made economic sense to adopt all of the machines, equipment and organizational techniques necessary to mass produce standardized goods with interchangeable parts. As noted, the few consumer durables producers in the US that adopted more fully the machines and methods of mass production, such as Remington and Brown and Sharpe, happened to be weapons and machine tool producers with first-hand experience applying the techniques sponsored and developed by the federal arsenals. Even these, however, could only occupy relatively small market niches in the 1860s and 70s when faced with competition from more labor-intensive producers.

As in the US, when British market size reach the point where the American System became profitable, this system was adopted. The first civilian application of American System principles on a wide scale in Britain was during the “bicycle boom” of the 1890s, when bicycles (invented in Britain) were popularized and mass-produced. Soon, mass production techniques were applied in Britain to the production of automobiles. Floud (1974), discussing the boom of American machinery exports to Britain in the 1890s, observes there is little indication that factor constraints were the cause of Britain’s failure to adopt American technology earlier: there was no sudden shift in factor costs or Britain’s resource endowment that would have made American techniques more profitable only in the 1890s but not before. Rather, as mentioned above, Floud argues American manufacturing had risen to maturity in the 1890s, proving itself capable of competing effectively on world markets. To this we may add that the emergence of mass demand in Britain, along with the crucial refinements in mass production techniques taking place in the US in prior decades, made the American System a viable strategy in Britain.

Of course, mass production techniques were adopted earlier in America, and the process of diffusion was much faster than in Britain. In some cases, this process may have been aided by more abundant supplies of wood and other resources in the US. In general, however, factor endowment discrepancies can explain neither the invention of mass production techniques nor the slower diffusion process in Britain. An obvious point missed by the neoclassical authros is that the diffusion of mass production techniques in America might have been faster simply because these techniques were American. That is, there were obvious advantages to American manufacturers of being located in the country where the machines, instruments and human expertise behind the American System originated. Rosenberg’s discussion of technical convergence is especially relevant here. America, and not Britain, was where the gun and machine tool producers who developed the American System were located. American manufacturers, thus, had a head-start and more direct access to the knowledge and technology of the System relative to European firms.

Notice that, though there were no restraints on the export of technology, it was not easy even for Britain's Enfield Arsenal, the first to introduce mass production techniques in this country, to adopt the American System. The arsenal, following the recommendation of the British inspectors discussed above, had to import substantial amounts of American machinery and technical expertise in the 1850s. Indeed, after buying the gunstocking machinery in use at Springfield—the centerpiece of which was the Blanchard lathe—the Enfield Arsenal hired an American mechanic to install it and direct its operations.

By the time Britain's Enfield Arsenal was just beginning to apply mass production techniques to weapons manufacture, many American manufacturers had knowledge of and at least some experience with special-purpose machines and the concept of interchangeability. They were thus much more prepared than British manufacturers to apply this knowledge to the production of sewing machines, typewriters and other goods.

American firms such as Remington and Brown and Sharpe were at the forefront of the process of techological convergence discussed by Rosenberg. Why did firms such as Remington not surface in England to produce sewing machines and typewriters with the productive techniques of the American system? Quite simply, there were no Remingtons in England. Remington, Pratt and Whitney and others were products of American armory practice, and it thus was they, and not the British, who were uniquely well-positioned to take advantage of their experience with what was soon to become the dominant production technique of the late 19th and early 20th centuries: mechanized, interchangeable manufacture.

Bibliography

Atack, J., Passell, P., *A New Economic View of American History, From Colonial Times to 1940,* 2nd edition, W.W. Norton and Company, 1994

Broadberry, S.N., Irwin, D.A., "Labor productivity in the United States and United Kingdom During the Nineteenth Century, Working Paper 10364, accessible at http://www.nber.org/papers/w10364, March 2004

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

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

_______, Abramovitz, M., "Two Centuries of American Macroeconomic Growth From Exploitation of Resource Abundance to Knowledge-Driven Development", Discussion Paper, STANFORD INSTITUTE FOR ECONOMIC POLICY RESEARCH, August 2001

Engerman, S.L., Sokoloff, K., “Technology and Industrialization, 1790-1914”, in Engerman, S.L., Gallman, R.E., (eds.), *Cambridge Economic History of the United States: The Long Nineteenth Century*, Cambridge University Press, 2000
Floud, R.C., The Adolescence of American Engineering Competition, 1860-1900, *The Economic History Review*, v. 27, n. 1, February 1974
Habakkuk, H.J., *American and British Technology in the 19th Century*, Cambridge, England, The University Press, 1962.
Harley, K., “Growth Theory and Industrial Revolutions in Britain and America”, *The Canadian Journal of Economics*, v. 36, n. 4, Nov., 2003), pp. 809-831
Hirschhorn, L., *Beyond Mechanization: Work and Technology in a Post-Industrial Age*, The MIT Press, 1986
Hounshell, D., *From the American System to Mass Production, 1800-1932*, Johns Hopkins University Press, 1984
McNeil, I., *An Encyclopedia of the History of Technology*, London, Routledge, 1996
Pope, C., “Inequality in the Nineteenth Century”, publicado em Engerman, S.L., Gallman, R.E., (eds.), *Cambridge Economic History of the United States: The Long Nineteenth Century*, Cambridge University Press, 2000
Rosenberg, N. "Technological Change in the Machine Tool Industry”, *Journal of Economic History*, Vol. 23, No. 4, dezembro de 1963, pp. 414-443
___________, “American Technology: Imported or Indigenous”, *The American Economic Review*, Vo. 67, No.1, Papers and Proceedings, February 1977, pp. 21-26.
Rosenbloom, D., “Anglo-American Differences in Small Arms Manufacturing”, *Journal of Interdisciplinary History*, Spring 1993, p. 687
Saul, S.B., “The Market and the Development of the Mechanical Engineering Industries in Britain, 1860-1914, *The Economic History Review*, v. 20, n. 1, April 1967
Soltow, L., “Wealth Inequality in the United States in 1798 and 1860”, *The Review of Economics and Statistics*, Vol. 66, No. 3, August 1984
________, “Inequalities in the Standard of Living in the United States”, publicado em Gallman, R.E., Wallis, J.J., (eds.), *American Economic Growth and Standards of Living Before the Civil War*, The University of Chicago Press, para o National Bureau of Economic Research, p. 121-66. 1992
Smith, M.R., *Military Enterprise and Technological Change: Perspectives on the American Experience*, The MIT Press, 1987
Smith, M.R., *Harpers Ferry and the New Technology*, Ithaca, NY: Cornell University Press, 1977
Temin, P., “Labor Scarcity and the Problem of American Industrial Efficiency in the 1850s”, Journal of Economic History, v. 26, n. 3, September 1966