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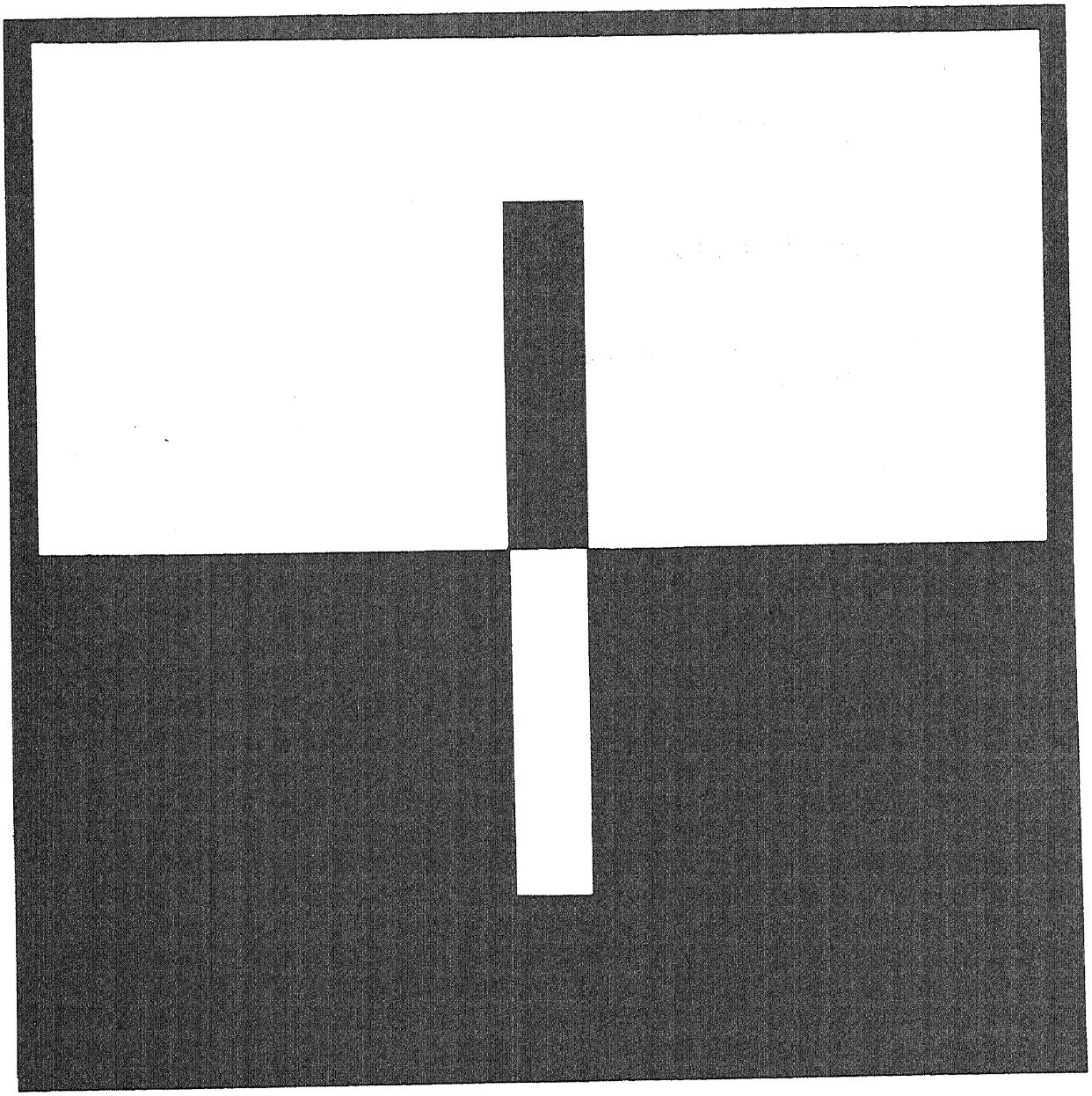

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Anglo-American Technological Differences in Small Arms Manufacturing

During the first half of the nineteenth century American manufacturers in a number of industries developed a distinctive method of production that has since come to be referred to as the American system of manufactures. These methods were most advanced in woodworking, precision metalworking, and small arms manufacturing, where the use of specialized machinery and elaborate systems of measurement made it possible to produce interchangeable parts that could be assembled without the extensive fitting and filing that was common in British industries at the time.[1]

The significance of these innovations is made clear by the interest manifested in them by contemporary British observers. In 1853 the British government dispatched several leading indus-

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The author especially thanks Paul David for introducing him to the 1840 United States Census data on small arms producers, and for his comments on earlier versions of this article. He also thanks Gavin Wright, Shane Greenstein, John Earle, Thomas Weiss, and an anonymous referee for their suggestions.

1 To nineteenth-century observers it appeared that the methods historians refer to as the American system had eliminated the need for skilled hand labor in assembling complex mechanisms such as firearms. Writing about the Springfield Armory in 1845, George Talcott observed, for example, that ". . . the skill of the eye and the hand of the old practical armorer is entirely dispensed with . . . the machines having effected a total revolution." Quoted in Robert B. Gordon, "Who Turned the Mechanical Ideal into Mechanical Reality?" *Technology and Culture,* XXIX (1988), 747. Recent work by historians of technology suggests, however, that the reality was more complex. Although mechanization was associated with a significant reduction in hand labor and an increase in precision, Gordon found that both physical and documentary evidence pointed to the continued importance of hand filing in shaping metal parts throughout much of the nineteenth century. For a description of the British discovery of American technological advances and the reproduction of the reports of British visitors to the United States, see Nathan Rosenberg (ed.), *The American System of Manufactures* (Edinburgh, 1969). David A. Hounshell, *From the American System to Mass Production, 1800–1932* (Baltimore, 1984), 15–65, provides additional background regarding nineteenth-century perceptions of American manufacturing technology.

trialists to study American methods firsthand, and several years later it undertook the establishment of a government-run armory employing American methods, equipped largely with American machinery. Describing the innovations that they had seen during their visit to the United States, members of the Committee on Machinery observed that:

> In consequence of the scarcity and high price of labor in the United States, and the extreme desire manifested by masters and workmen to adopt all labour-saving appliances . . . a considerable number of different trades are carried on . . . in large factories, with machinery applied to almost every process, the extreme subdivision of labour and all reduced to an almost perfect system of manufactures.[2]

Although there now exists an extensive literature attempting to explain the divergence of American and British manufacturing techniques during the nineteenth century, less attention has been devoted to the extent to which the so-called American system was diffused throughout the United States economy. I use data on the structure of the American small arms industry, drawn from the 1840 and 1850 censuses of manufacturing, to trace the diffusion of the American system within this industry. The data indicate that as late as 1840 the techniques noted by British observers in the 1850s had been adopted only in government armories and within the small circle of manufacturers producing weapons on contract for the United States government; outside of this circle there persisted a large number of artisanal shops employing more traditional methods of production.[3]

The importance of the military in promoting the development of interchangeable parts production and other aspects of the American system has been recognized by historians of technology for some time. What has not previously been noted, however, is

2 *Report of the Committee on the Machinery in the United States of America: Presented to the House of Commons in Pursuance of Their Address of the 10th July 1855,* in Rosenberg, *The American System,* 128.

3 Small arms production was only one of a number of industries in which the American system was visible. However, small arms manufacturers are widely regarded as having introduced many of the techniques that characterized the American system, and British observers devoted much of their attention to small arms manufacturers, suggesting that if they could understand the development of that one industry it could shed light on developments in other industries as well. On the importance of small arms manufacturing in the development of the American system, see Rosenberg, *American System,* 66–72; Hounshell, *From the American System,* 4–5, 15–65.

the slow diffusion of the techniques of the American system beyond government armories and government contractors, and the persistence of a substantial traditional sector as late as the middle of the nineteenth century. These facts are significant because they are inconsistent with the explanations most commonly advanced by economic historians for the emergence of the American system, which assume that it represented an optimal response to general macroeconomic conditions in the United States.[4]

Despite the detailed descriptions provided by British observers at the time, economic historians have not been able to agree about precisely how to characterize the differences between American and British manufacturing techniques. From the perspective of modern economic theory, nineteenth-century descriptions can be interpreted in two conceptually distinct ways: (1) Americans used *more* machinery, or (2) Americans used *better* machinery than their British counterparts. Whichever interpretation they have favored, however, most economic historians have attempted to explain the divergence of American and British technology as the consequence of differences in relative factor abundance between the two countries. Proponents of the view that Americans used more machinery have explained this choice as a simple substitution along the unit isoquant in response to the relative abundance of land and the consequent higher cost of labor in the United States. Proponents of the better machinery interpretation have argued that initial differences in factor proportions were transformed into differences in technology through a process of localized learning.[5]

4 Despite the common interest of economic historians and historians of technology in the origins of the American system, research in each discipline has proceeded largely in isolation from the other. Whereas historians of technology have amassed considerable evidence of the importance of military sponsorship in the development of the American system, they have not directly confronted the hypotheses commonly advanced by economic historians to explain the emergence of the American system. On the importance of the military in promoting interchangeability see Merritt Roe Smith, *Harpers Ferry Armory and the New Technology: The Challenge of Change* (Ithaca, 1977); *idem*, "Army Ordnance an the 'American system' of Manufacturing, 1815–1861," in *idem*, (ed.), *Military Enterprise and Technological Change: Perspectives on the American Experience* (Cambridge, Mass., 1985), 28–46; Hounshell, *From the American System*.

5 H. J. Habakkuk, *American and British Technology in the Nineteenth Century: The Search for Labour-Saving Inventions* (Cambridge, 1962) is largely responsible for initiating discussion of the American system among economic historians. Peter Temin, "Labor Scarcity and the Problem of American Industrial Efficiency in the 1850s," *Journal of Economic History*, XXVI (1966), 277–298; *idem*, "Labor Scarcity in America," *Journal of Interdisciplinary History*, I (1971), 251–264, suggested the distinction between the more machines and

Ames and Rosenberg offer one of the few exceptions to the supply-side approach typical in most explanations of the American system. They argue instead that mass-produced American rifles were a qualitatively different product from the handcrafted guns turned out by British artisans and that it is fruitless to attempt to characterize production methods in terms of aggregate capital-labor ratios. Instead, they suggest that the choice of different production methods in the two countries might reflect the larger size of the American market and the greater willingness of American consumers to purchase standardized, mass-produced products.[6]

Despite disagreement about what needs to be explained and how to explain it, all of these accounts assume that the techniques characteristic of the American system were an optimal response to the circumstances in which American manufacturers found themselves. If so, then the expectation is that in the absence of high transportation cost barriers, producers using traditional handicraft methods would eventually be driven out of business by their lower cost competitors. That this did not occur raises serious questions about the ability of macroeconomic conditions, such as relative factor abundance or the characteristics of consumer demand, to explain the course of development of American manufacturing technology in the nineteenth century. Rather, I will

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better machines hypotheses, and examined the conditions under which land abundance and labor scarcity will in fact lead to a higher capital-labor ratio. For further discussion of this topic see Robert Fogel, "The Specification Problem in Economic History," *Journal of Economic History,* XXVII (1967), 283–308; Paul Uselding, "Studies in Technology in Economic History," in Robert E. Gallman (ed.), *Recent Developments in the Study of Business and Economic History: Essays in Memory of Herman E. Kroos* (Greenwich, Conn., 1977), 159–220. The principal complication that the factor substitution argument must confront is the evidence that at least at the aggregate level Americans actually used less capital per worker than did the British, and that interest rates as well as wages were higher in America than in Britain. On aggregate capital-labor ratios, and the appropriateness of interpreting Anglo-American differences in this way, see Alexander James Field, "Land Abundance, Interest/Profit Rates, and Nineteenth-Century American and British Technology," *Journal of Economic History,* XLIII (1983), 405–431; *idem,* "On the Unimportance of Machinery," *Explorations in Economic History,* XXII (1985), 378–401. John A. James and Jonathan S. Skinner, "The Resolution of the Labor-Scarcity Paradox," *Journal of Economic History,* XLV (1985), 513–540, offered one possible resolution to this problem. Paul A. David, *Technical Choice, Innovation and Economic Growth: Essays on American and British Experience in the Nineteenth Century* (Cambridge, 1975), 19–94, is the principal statement of the better machinery interpretation. An isoquant is the set of inputs that give rise to a constant quantity of output.

6 Edward Ames and Rosenberg, "The Enfield Arsenal in Theory and History," *Economic Journal,* LXXVIII (1968), 827–842.

show that the 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. Only after an extended period of gestation under military sponsorship did the techniques developed in producing firearms for the military become attractive to manufacturers serving the private market. Although it is difficult precisely to identify the point at which armory methods became competitive in the production for the private sector, the transition appears to have occurred by the early 1850s.[7]

THE STRUCTURE OF THE AMERICAN SMALL ARMS INDUSTRY The published returns of the 1840 and 1850 censuses of manufactures depict fairly accurately the structure of the American small arms industry. Whereas these sources do not contain information about the methods of production used by different manufacturers, they do contain information on the scale of production at different establishments. Because interchangeable parts production entailed large fixed costs for the construction of special purpose machinery and the implementation of elaborate systems of measurement, it could only have been practical at a relatively large scale of production. Thus size may be used as a proxy for the method of production.[8]

The published returns of the 1840 census are particularly illuminating because they provide information on the number of persons employed and the number of guns produced at the township or county level. The 1850 census returns provide considerably more detailed information—the value of production, the cost of raw materials, the value of capital employed, and the number of men and women employed—but the published returns are aggregated at the state level, making it impossible to determine the size of individual establishments. Some aggregation is probably inevitable in the 1840 census as well, but it is likely that in

7 Hounshell, *From the American System*, 46–50, argued that the opening of the new Colt Armory in Hartford, Connecticut, in 1855 marked the beginning of the successful application of armory practice to production primarily for the private market.

8 The data are from U.S. Department of State, *The Sixth Census, 1840* (Washington, D.C., 1841); U.S. Department of the Interior, *Abstract of the Statistics of Manufactures, Seventh Census, 1850* (Washington, D.C., 1858).

most cases only one establishment was present in a township or county. To the extent that aggregation is a problem, however, it will bias the case in favor of finding larger establishments. Since I argue that there were few large establishments, I take each observation to represent a single establishment.

Several sources of inaccuracy are present in the census data. First, the census coverage was probably incomplete. However, since small producers were the ones most likely to be missed by census enumerators, there is little risk that establishments large enough to have employed interchangeable parts production methods would not have been counted. Second, the data reported may be incorrect. For 1840 it was possible to test for the internal consistency of the data reported for each observation, thus I was able to correct thirteen observations.[9]

The 1840 census shows that guns were produced in at least 306 locations in 25 states. The size of these establishments can be measured in terms of either employment or production. Table 1 shows the size distribution of gun producers for both these measures, assuming that each observation represents a single establishment.

The two largest establishments by either criterion were the federal armories at Springfield and Harpers Ferry. Combined, they accounted for 22,850 guns, or more than one-third of total United States production, and 522 workers. Almost all of the private producers were small. In only one-sixth of the other locations did employment exceed four workers. Employment exceeded ten workers in just twenty places, and in only eight of these were more than twenty men employed in gun making. These same eight locations were the only ones in which produc-

9 To check the internal consistency of the observations, I computed the labor productivity implied in each case by dividing the number of guns produced by the number of employees plus one (to take account of the proprietor's labor). The average labor productivity was 27.26 guns with a standard deviation of 63.08. It seems safe to assume that the 13 observations with productivities more than one standard deviation above the mean (all of them greater than 130) were the result of errors in recording or reporting. In all cases it appeared that the number of guns produced had been inflated by an order of magnitude. To confirm this conclusion I checked the listing of gun makers compiled by Leroy D. Satterlee and Arcadi Gluckman, *American Gun Makers* (Buffalo, 1940) to see that there were no major gun makers in any of the locations that had establishments with unusually high productivities. To correct these observations I used the number of guns reported in the census divided by 10.

Table 1 The Size Distribution of Small Arms Producers in 1840

SIZE	NUMBER OF OBSERVATIONS	PERCENTAGE OF OBSERVATIONS	TOTAL GUNS PRODUCED
Number of Employees			
0–1	118	38.6	2,485
2	84	27.5	3,468
3	29	9.5	2,305
4	23	7.5	2,113
5–9	30	9.8	5,309
10–19	12	3.9	4,801
20–29	8	2.6	21,782
240	1	0.4	8,850
280	1	0.4	14,000
Number of Guns Produced			
0–24	106	34.6	1,346
25–49	61	19.9	1,963
50–99	60	19.6	3,732
100–499	66	21.6	11,786
500–999	3	1.0	2,054
1,000–2,499	5	1.7	8,950
2,499–8,000	3	1.0	12,832
8,850	1	0.4	8,850
14,000	1	0.4	14,000

NOTES Distributions computed under the assumption of one establishment per location. Thirteen observations corrected as described in the text. Percentages may not sum to 100 because of rounding.

SOURCE U.S. Department of State, *Sixth Census, 1840* (Washington, D.C., 1841).

tion exceeded 1,000 guns in 1840, whereas production in only three other places exceeded 500 guns.

Of the eight locations with the largest private employment and production of guns, six clustered near the Springfield Armory—two in Massachusetts, three in Connecticut, and one in Vermont. The remaining two locations were Albany, New York, and Paterson, New Jersey. In contrast to the close proximity of the largest private centers of production to the government armories, medium-sized centers of production, those places with employment of ten to nineteen workers, were mostly located near western and southern markets. Establishments in New York and Philadelphia employed more than ten men each, but the other locations with employment in the ten-to-nineteen range were in

rural Pennsylvania (five places), Kentucky (two places), Virginia, and Alabama (one place each).[10]

Many of the small establishments that are listed in the census were located in remote areas, but a considerable number of them operated in close proximity to much larger establishments, suggesting that transportation cost barriers alone cannot account for their survival. In Massachusetts and Connecticut, for example, there were nine establishments employing from one to five persons, and producing less than 120 guns per year. Many more small producers were located in the surrounding states of New York, Vermont, and New Hampshire, which were served by a well-developed transportation system by this date.

To translate information on the size of small arms producers into a measure of the diffusion of the American system, it is necessary to know how big an establishment had to be to recoup the fixed costs of interchangeable parts production. Several rough measures of this size are possible. At the Springfield Armory, where the methods necessary to ensure precise measurement were pioneered, their introduction necessitated an extensive division of labor. Prior to the introduction of these methods, eleven distinct occupations were employed at the armory, but the development of a system of gauges and fixtures capable of producing interchangeable parts led to an increase in the number of occupations to thirty-four in 1815, eighty-six in 1820, and 100 in 1825. By this standard just eight establishments were large enough to implement the division of labor employed at Springfield in 1815. Even if we suppose that as few as seventeen employees—half the number of occupations at Springfield in 1815—were necessary to implement the system employed at the armory, the number of establishments capable of interchangeable parts production would increase to only eleven.[11]

10 The eight largest centers of production outside the federal armories were (with employment in parentheses): Millbury, Mass. (71); Middletown, Conn. (70); Paterson, N.J. (70); Weathersfield, Conn. (40); Windsor, Vt. (40); Albany, N.Y. (35); Pittsfield, Mass. (30); Hamden, Conn. (30). The likely identities of producers in these locations are discussed below in n. 13. In addition to New York and Philadelphia, the locations with employment of 10–19 workers were: Lancaster, West Cocalico, Comro, Bushkill, Spring in Pennsylvania; Louisville, Washington in Kentucky; Guilford, Virginia; Lauderdale, Alabama.

11 Felicia Johnson Deyrup, "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,* XXXIII (Northampton, Mass., 1948), 90–91.

On the basis of production, a minimum of 1,000 guns would appear to be a conservative estimate of the level of production necessary to justify the expense of interchangeable parts production. In the 1830s, John Hall, who was producing a breech-loading rifle using a number of machines of his own invention, complained that because the government would only contract for 1,000 rifles a year his costs were considerably higher than they might be at a higher volume. In fact, he estimated that he could produce nearly three times as many rifles at little additional cost. Using this criterion, only eight of the private producers of small arms would have been capable of employing the techniques of the American system. Even if we were to lower the threshold scale to 500 guns a year, this number would only increase by three.[12]

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. From biographical material on American arms makers collected by Satterlee and Gluckman, it is possible to identify the manufacturers in six of the eight locations in which 1,000 or more guns were produced, and in four of those locations the manufacturers had contracts with the military in 1840. Moreover, the two manufacturers who did not have government contracts both failed in 1842, confirming the central role of military demand in making large-scale production methods viable.[13]

By 1840 the technological foundations of the American method of small arms production were already well established. It is possible, however, that producers employing traditional pro-

12 Smith, *Harpers Ferry Armory*, 37.

13 The producers listed as government contractors by Satterlee and Gluckman were: Asa Waters, Millbury, Mass.; Nathan Starr, Simeon North, Robert Johnson, Middletown, Conn.; Lemuel Pomeroy, Pittsfield, Mass.; P. & E. W. Blake, Hamden, Conn. Only Samuel Colt, Paterson, N.J. (producing 2,000 guns) and Kendall & Co., Windsor, Vt. (producing 1,000 guns) do not appear to have had government contracts. No entries could be located for gun makers in either Albany, N.Y. or Weathersfield, Conn., the two other locations for which production of more than 1,000 guns was reported.

Colt's Patent Arms Manufacturing Company failed in 1842 due to "lack of public and government support." Kendall & Co. also ceased operations in 1842, although the reasons why the firm gave up gun production are not clear. Several years later Nicanor Kendall joined with Samuel E. Robbins and Richard S. Lawrence to establish the firm of Robbins, Kendall & Lawrence, which in 1845 received a substantial government contract for the production of the Model 1841 rifle. Satterlee and Gluckman, *American Gun Makers*, 22, 32, 80, 84, 115–116, 127, 136, 154, 171–172.

duction methods responded only slowly to the competitive pressures created by the large-scale producers. If these competitive pressures indeed existed, we would expect them to be reflected in changes in the structure of the industry over the succeeding decade.

The published returns of the 1850 census are too highly aggregated to permit inferences about the persistence of individual establishments, but it is possible to compare average employment and production by state in 1840 and 1850. As Table 2 shows, there was remarkably little change at this level during the 1840s. In most of the New England and Mid-Atlantic states the number of establishments did fall, but the effect of this consolidation resulted in an increase in average employment in just slightly less than half of the states in these regions.[14]

The survival as late as 1850 of many gun producers, who were too small to have employed the techniques of the American system, suggests that if there were any cost savings associated with the adoption of these methods in production for the civilian market, they were modest. To further understand this question I used data from the 1850 census directly to estimate the extent of any economies of scale that did exist. Assuming a Cobb-Douglas production function, value added per worker (V/L) can be written as $V/L = A(K/L)^{a}L^{b}$, where A is a constant, K/L is the capital-labor ratio, and L is the number of workers. Taking logarithms of both sides of this expression produces a linear specification that can be estimated by ordinary least squares. A regression across states using the 1850 data yields (t-statistics in parentheses):

$$\log(V/L) = \underset{(5.466)}{4.838} + \underset{(1.458)}{0.743}\log(K/L) + \underset{(0.854)}{0.042}\log(L) \qquad R^2 = .119$$

The coefficient on log(L) is a direct measure of the extent of any economies of scale. The estimated value of this coefficient in 1850 is quite small, and the null hypothesis that is equal to zero cannot be rejected at standard confidence levels. Thus, it appears that at least as late as 1840, and possibly 1850, adoption of the methods

14 Alternatively, the persistence of traditional production methods could be explained if they were used to produce a qualitatively different product than the military weapons produced by government armories and contractors.

Table 2 Number of Establishments and Average Employment by State in 1840 and 1850

	1840		1850	
STATE	NUMBER	AVERAGE EMPLOYMENT	NUMBER	AVERAGE EMPLOYMENT
NEW ENGLAND				
Maine	2	2.0	0	—
New Hampshire	2	3.5	2	1.5
Massachusetts	12	33.1	10	21.0
Rhode Island	0	—	1	2.0
Connecticut	6	24.7	8	38.1
Vermont	5	8.4	2	3.5
MID-ATLANTIC				
New York	64	3.1	46	6.2
New Jersey	2	36.0	3	3.0
Pennsylvania	58	3.0	55	4.8
Maryland	1	3.0	11	7.4
Washington, D.C.	0	—	1	3.1
MIDWEST				
Ohio	28	2.5	29	2.8
Indiana	22	2.1	24	1.6
Illinois	11	1.1	14	1.6
Iowa	1	2.0	2	2.0
Missouri	10	4.8	24	1.7
Michigan	3	2.0	3	1.7
Wisconsin	1	1.0	4	1.3
SOUTH ATLANTIC				
Virginia	11	23.8	14	3.1
North Carolina	0	—	9	2.1
South Carolina	2	3.5	3	2.7
Georgia	4	1.3	10	2.8
SOUTH CENTRAL				
Alabama	1	16.0	2	2.0
Mississippi	5	1.4	1	1.0
Tennessee	12	2.8	15	2.1
Kentucky	33	3.2	22	2.0
Arkansas	1	1.0	0	—

SOURCES U.S. Department of State, *Sixth Census, 1840* (Washington, D.C., 1841); U.S. Department of the Interior, *Abstract of the Statistics of Manufactures, Seventh Census, 1850* (Washington, D.C., 1858).

of production characteristic of the American system conveyed little or no competitive advantage to small arms manufacturers.[15]

EXPLAINING THE EMERGENCE OF THE AMERICAN SYSTEM If the development of the American system in small arms production

15 Value added is computed as the difference between the reported value of output and

did not represent an optimal adaptation to supply or demand conditions, as the survival of small manufacturers employing more traditional techniques indicates, why did mechanization and interchangeable parts production emerge in the United States during the first half of the nineteenth century? The answer, as suggested by the fact that virtually all of the producers large enough to be employing the methods of the American system were government contractors, lies in the role of United States military demand for guns during this period.

Until the end of the eighteenth century, the United States remained largely dependent upon European suppliers to outfit its armed forces. In the 1790s, however, growing hostility between the United States and France prompted federal efforts to establish a domestic source of supply. Federal armories were established at Springfield and Harpers Ferry, and Congress appropriated $800,000 for the purchase of cannon, small arms, and ammunition from private arms makers. The few skilled gunsmiths in the country were ill-equipped to respond to the huge volume of production required by the government, however, and most of the government's contracts went to enterprising manufacturers from other industries, such as Eli Whitney, who were attracted by the large sums of money involved. The government's decision to offer large contracts and allow contractors generous advances against them was in Deyrup's judgment extremely important in establishing early private manufacturers on an "industrial foot-

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the cost of raw materials. The labor input is the number of male employees (no women were employed in any of the establishments), and the capital input is the value of the capital stock reported in the census. The true relationship between productive efficiency and scale may possibly be masked by the aggregation of the data. If, however, across-state variations in size were more important than within-state variations, then it will be possible to use the aggregated data. See John A. James, "Structural Change in American Manufacturing, 1850–1890," *Journal of Economic History,* XLIII 43 (1983), 457–458, which uses state average data for a number of industries to estimate economies of scale in the nineteenth century. The specification of the production function is identical to that used in Kenneth L. Sokoloff, "Was the Transition from the Artisanal Shop to the Nonmechanized Factory Associated with Gains in Efficiency?: Evidence from the U.S. Manufacturing Censuses of 1820 and 1850," *Explorations in Economic History,* XXI (1984), 351–382. The results in the text are consistent with estimates of the more conventional specification of the production function, which yields (t-statistics in parentheses):

$$\log(V) = \underset{}{5.430} + \underset{(10.80)}{0.919}\log(L) + \underset{(8.956)}{0.122}\log(K) \qquad (1.392)$$

$$R^2 = .954$$

which also indicates that economies of scale were insignificant.

ing," because the certainty of a steady income made possible and desirable the heavy investments that large-scale production required.[16]

From the beginning the government urged contractors to develop methods of production using interchangeable parts. The idea of interchangeability, or "uniformity" as it was most commonly called at the time, has been traced to the French military, where it emerged sometime during the 1760s as part of a larger effort to rationalize the French army. American interest in the idea was likely stimulated by the presence of French military advisors during the American Revolution. In addition, Thomas Jefferson, who had learned of French efforts to implement interchangeability during his stay in France, became an early advocate of this goal at the highest levels of government. Despite this interest, little progress toward interchangeability was made before 1810.[17]

The expansion of demand during the War of 1812 combined with the shortage of skilled gunsmiths led government contractors to search for ways of substituting less skilled for skilled artisans. To make use of less skilled workers they were obliged to develop a variety of gauges and fixtures to guide their work. Along with these new methods of measurement they introduced an extensive division of labor encouraging specialization along narrow functional lines. An additional factor that may have encouraged progress toward interchangeability at this time was its practicality in light of the large stock of damaged weapons left unusable during the war. Their repair required the attention of a master gunsmith.[18]

Both private contractors and the federal armories contributed to the development of new production methods after 1812. It was the federal armory at Springfield that perfected most of them,

16 Deyrup, "Arms Makers," 36–38. On Whitney's motivations for seeking government contracts for the production of small arms see Robert S. Woodbury, "The Legend of Eli Whitney and Interchangeable Parts," *Technology and Culture,* I (1960), 235–253; Hounshell, *From the American System,* 31.

17 Hounshell, *From the American System,* 25–27; Smith, "Army Ordnance."

18 Deyrup, "Arms Makers," 87–88; Smith, *Harpers Ferry Armory,* 106–112. Gordon, "Mechanical Ideal," 769–777, argued that the increased division of labor and the introduction of more elaborate systems of measurement in precision metal-working did not so much eliminate the need for skilled labor as substitute one set of skills for another. All-around craft skills became less important, but new skills—especially manual dexterity and resourcefulness in dealing with variations in the quality of materials—remained important qualifications for artificers.

developing an elaborate system of gauges to assure the nearly complete uniformity of components. Subsequently the armory lent its master copies to private contractors so that they could reproduce them.[19]

The introduction of better methods of making critical measurements was followed by efforts to mechanize the production process. At first these concentrated mainly on the shaping of gun barrels, which was difficult and hazardous to do by hand. Between 1816 an 1819 at least five different barrel-turning machines were developed by both private contractors and mechanics at the federal armories. One of the most promising of these was developed by Thomas Blanchard, a mechanic employed by Asa Waters, a government contractor. By tracing out the shape of a master pattern, Blanchard's machine could shape both the cylindrical and flat portions of the barrel. Government inspectors related the details of Blanchard's innovation to Roswell Lee, the director of the Springfield Armory, and a contract was soon signed for the construction at the armory of several machines based on the same principle.[20]

Recognizing the broader applicability of the methods embodied in his barrel-shaping machine, Blanchard applied them to a series of machines designed to produce irregularly shaped wooden gunstocks. Shortly after seeing a demonstration of these machines, Lee put Blanchard on the armory payroll. Even though Lee believed that the machines already developed by Blanchard would reduce the cost of producing gunstocks, he emphasized that the "principal object is to bring the machinery to the most perfect state." In other words, Lee believed that government support was necessary to promote the development of a technology that was unlikely to receive further support from the private sector. From his arrival at Springfield in 1823 until 1827, Blanchard steadily elaborated and improved upon his original invention, ultimately producing fourteen separate machines to carry out different steps in the production of gunstocks.[21]

19 Deyrup, "Arms Makers," 89, 91–92.

20 Smith, *Harpers Ferry Armory,* 112–113, 125–126; Deyrup, "Arms Makers," 93–94.

21 For a detailed description of Blanchard's contributions see Carolyn C. Cooper, *Shaping Invention: Thomas Blanchard's Machinery and Patent Management in Nineteenth-Century America* (New York, 1991). On the role of government sponsorship of Blanchard's innovations see Smith, *Harpers Ferry Armory,* 127–128, 134–135. The development of the Blanchard lathe was not the only instance in which the government directly supported research and development aimed at improving methods of producing small arms. Another notable

With the perfection of methods of measurement and major breakthroughs in the construction of special purpose machinery, the major technical foundations of the American method of small arms production were established by the early 1830s. As the capacity of the federal armories grew, the Army Ordnance Department became increasingly dissatisfied with its contract system, charging that the quality of the privately supplied weapons was lower than that of those produced at the armories, whereas their cost was greater. Yet, uncertainty about future contracts made private producers increasingly reluctant to make the substantial investments in new tools and machinery needed to keep up with modifications in the design of military weapons, and many of them eventually abandoned small arms manufacturing altogether. While the government contractors were disappearing during the late 1830s and 1840s, a new group of manufacturers—epitomized by patent arms makers like Samuel Colt; Robbins, Kendall, & Lawrence; and E. Remington & Sons—began to adapt the armory techniques to production for the private market. But it was only at this time that these techniques first began to appear commercially viable in the private market. Without government sponsorship and inducements, it appears unlikely that private producers would have developed such methods in nonmilitary markets.[22]

In contrast to the early and continuing involvement of the United States government in the production of small arms, the British government relied almost entirely on contracts with private producers and made no effort to induce them to develop new production methods. Although meeting large wartime demand for guns strained the capacity of private producers in Britain as it did in the United States, British producers were better equipped

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example is the support provided to John Hall, an extremely important contributor to the development of techniques for shaping metal components crucial to the achievement of effectively interchangeable parts production. See *Ibid.*, 184–251, for an extensive discussion of Hall's contributions and the role of government support in their achievement.

22 Hounshell, *From the American System*, 46–50. Interestingly, even when the patent arms producers did adopt armory methods they often did not attempt to achieve the level of interchangeability upon which the Army Ordnance Department had insisted. Examination of pistols produced for the private sector around 1860 shows that parts could not be readily interchanged. The level of precision required was simply too costly and the private demand for interchangeability too limited for it to be economically rational. See Robert A. Howard, "Interchangeable Parts Reexamined: The Private Sector of the American Arms Industry on the Eve of the Civil War," *Technology and Culture*, XIX (1978), 633–649.

to meet military demand than were the few small American producers. By the late eighteenth century, the Birmingham area had emerged as one of the world's leading centers of small arms production. As military demand expanded, gunsmiths employed in production for the private market could switch to the more lucrative military trade, and skilled craftsmen could be recruited from other metal-using industries that concentrated around Birmingham. Nonetheless, the British military expressed continuing dissatisfaction with the quality and price of guns purchased from private producers. Their efforts to establish government armories had to contend, however, with the presence of a large and well-established private industry that successfully lobbied to prevent any departure from the use of private contractors.[23]

Economic historians have sought to explain the divergence of American and British manufacturing technologies during the first half of the nineteenth century as a consequence of optimal adaptation to differences in either factor abundance or consumer demand. Examination of the structure of the American small arms industry between 1840 and 1850 indicates, however, that the introduction of mechanized production using interchangeable parts conveyed little or no competitive advantage. Historians of technology have long recognized that military demand played an important role in fostering the development of the manufacturing techniques that struck mid-century British observers as so startling, but the evidence presented here confirms that without military sponsorship the private sector would have been unlikely to develop these methods. Only around the middle of the nineteenth century did the techniques of the American system become competitive in production for the private market. On the one hand, this suggests that there is less to explain about Anglo-American technological differences than first appears. On the other hand, it reinforces the view that the development of new technologies is a path-dependent process in which historical accidents can significantly alter the course of economic development.

23 This paragraph draws heavily on the discussion of the British small arms industry in Rosenberg, *American System*, 30–36, 39. See also, Russell I. Fries, "British Response to the American System: the Case of the Small-Arms Industry after 1850," *Technology and Culture*, XVI (1975), 377–405.