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The Continuity of Wartime Innovation: The Civil War Experience

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Capitalist development involves ongoing technological change in which a series of innovations develop and diffuse. Wars and other discontinuities thwart some innovations and generate others. Wartime experience illuminates the issue of whether innovation responds to the changing economic environment or maintains earlier directions. I examine the development of Civil War innovations in firearms, shoe mechanization, and petroleum. Using patent data, government procurement records, and firm records, I argue for the continuity of innovative content and in the occupation, network status, and location of patentees. Wartime innovation evolved out of antebellum firms, networks, and inventors, drawing on machinists, engineers, and applied scientists to transfer critical antebellum capabilities into innovating sectors. The war accelerated innovations in firearms and shoe mechanization, but it may have slowed petroleum innovation. Because antebellum innovation developed and spread knowledge in a wide variety of areas, innovations could come to fruition at the same time, even though they competed for some of the same resources.

Ongoing technological change is an essential component of capitalist development. Practitioners simultaneously diffuse and improve innovation in many fields and generate innovations in new fields. Demand growth offers incentives, and expanding capabilities supply the innovations. Yet discontinuities periodically break the process. Plummeting demand and investment, sudden changes in resource availability or prices, and massive labor force changes all can interrupt innovation. Few discontinuities are more abrupt than wars. Wars can fundamentally shift demand, redeploy labor, change the very agents and organization of the innovation process, and so can support some innovations and thwart others. Wartime experience hence illuminates the extent to which innovation responds to the changing economic environment or, propelled by internal dynamics, follows earlier paths.

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The Civil War was one such cataclysm. It was the most destructive war in American history, killing 2 percent of the population. In the North, a quarter of the labor force served in the military at some point during the war. Federal government military purchases skyrocketed. The government organized much military provisioning and even military production. Southern markets and materials were lost. The growth of industrial production, slowed from the mid-1850s, recovered little until midway in the war.[1] Shifts in the profitability of innovations and a deployment of capabilities toward military targets might have altered the basic direction of innovations, propelling some and limiting others. Such changes might have been especially important in an economy that only recently formed the capabilities to sustain innovation in some industries and extend it to others.

Yet wartime innovation persisted across a wide front. Engines, sewing machines, harvesters, and printing presses continued to develop. Mass-production applications deepened and spread, and wholly new innovations arose in shoemaking, illuminants, and elsewhere. Innovation proved both continuous and flexible. It continued along existing paths even as wartime needs changed the structure of demand and the allocation of labor. However, it was capable of redirection toward some innovations and away from others. Flexibility and continuity could have been opposing alternatives if redeployment of resources starved existing innovation paths or if existing paths could not meet wartime needs. In fact, continuation along existing paths and redirection along new paths did not preclude each other. Indeed, in ways redeployment to wartime needs strengthened existing dynamics, and those dynamics helped meet wartime needs.

Two kinds of capabilities formed before the war help account for innovation's continuity and flexibility. One was universal knowledge, applicable to many sectors, which innovators could redeploy among them. Machinists, engineers, drafters, and patent agents formed technological centers that had come to spread knowledge widely among industries. Their action enabled rapid movement from civilian to military sectors to meet wartime needs. A second capability was industry-specific, embodied in networks with particular knowledge, and hard to redeploy. Such networks might have thwarted shifts in innovation, yet sustained existing innovational paths.

Both continuity and flexibility had characterized ongoing innovation since 1835. Along innovation paths, networks structured invention among the same groups and locations. Technological occupations with universal knowledge helped generate innovations such as locomotives, sewing machines, reapers, and telegraphs. Innovative processes then developed their own dynamics. Their economic contexts of course mattered, affecting potential demands and

[1] The slowdown of growth began earlier; growth over the 1855-1865 decade was about one-quarter as fast as the remarkable 120 percent of the previous decade. Joseph H. Davis, "An Annual Index of U.S. Industrial Production, 1790-1915," *Quarterly Journal of Economics* 119 (Nov. 2004): 1172-1215, especially p. 1189.

costs. However, innovation paths had an internal logic propelling them forward.

Wartime innovations followed paths begun under very different circumstances. The Civil War fundamentally maintained antebellum innovational dynamics in the North. The content of innovation, the pace of patenting, and the occupation, network status, and location of patentees remained much the same. The economic circumstances of wartime innovations varied greatly. Demand skyrocketed for firearms but fell for shoes and illuminants. Yet firearms manufacturing, shoe mechanization, and petroleum production each expanded rapidly. The war affected the pace of innovation, but each innovation continued along antebellum paths, using particular knowledge and redeploying resources from related sectors. As documented by government procurement records, patent and patent assignment data, firm records, and technological, business, and economic histories, universal and particular capabilities, embedded in industry networks and technological centers, sustained and redirected wartime innovation in the North.

Multiplying Armaments

The Civil War marked a great discontinuity in economic life. The separation of North from South dislocated markets and sources of supply. The two million Northerners serving in the military disrupted the labor supply. At the same time, governments required huge increases in munitions and other supplies; the U.S. Army increased its materiel purchases from under $10 million in 1860 to $628 million in 1865. Some goods required little alteration, such as apparel and wagons, allowing redeployment of resources within industries. Increasing annual ordnance purchases from $1.5 to $43 million, however, required a huge increase in capacity, much of it in new products.[2] The North's ability to augment and improve wartime production affected the war's outcome. It also manifested the adaptability of technological capabilities formed over the previous decades.[3]

The scale and speed of redeployment rested on the capabilities of industries and technological centers. Major innovators listed in biographical dictionaries demonstrated the depth of redeployment. One-quarter of those who were active during the war produced or invented military firearms, ordnance, warships, machinery to make them, or new products for government contracts (see Table 1). Revealingly, all but two were located in the North. The continuity of war-related innovators was clear: over half continued lines of production and invention begun before the war, including engineers and manufacturers of firearms, steam engines, ships, locomotives,

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[2] Mark R. Wilson, *The Business of War: Military Mobilization and the State, 1861-1865* (Baltimore, Md., 2006), 38.

[3] Parts of this paper are drawn from Ross Thomson, *Structures of Change in the Mechanical Age: Technological Innovation in the United States, 1790-1865* (Baltimore, Md., forthcoming, 2009), especially chap. 10.

TABLE 1
Civil War Contributions by Major Innovators

Background Machinery	Number[a]	Production	Invention
Generic	8	firearms (2); cannon	rifling; firearms (3), machinery, revolving turrets
Machine Tools	5	firearms machinery (4)	firearms
Steam Engines	10	boat engines (7), Monitor, ship engineer; machinery	firearms (2); Monitor
Steamships	2	steamships (2); gun carriage	firearms; steamship
Locomotives	1	Military locomotives	
Printing Presses	2	firearms machinery (2)	
Textile Machinery	4	firearms (3); machinery	firearms (3)
Sewing Machines	1	gunpowder (Confederate)	
Shoemaking	2	military footwear	
Woodworking	2	rolled plates, bayonets	bayonets; firearms
Other Metalworking			
Foundry	5	Cannon balls; horseshoes; cannon; iron plate (2)	rifled cannon
Hardware	1	cannon	projectiles
Firearms	9	firearms (8)	firearms (5)
Brassmaking & lamps	2		firearms; warships
Wire Drawing	1		ordnance
Crafts			
Condensed Milk	1	condensed milk	
Artificial limbs	1	artificial limbs	artificial limbs
Shipbuilding	1	lifeboats	watertight wagon-boat
Science & Invention			
Civil Engineer	8	maps; military railroad (2), naval engineer	firearms (2); projectiles; boats; torpedoes
Army Engineer	3	Ordnance Dep't (3; 1 Confederate)	firearms; gunpowder

Naval Engineer	2	Ordnance Dep't; Naval engineer	cannon; warships
Chemist	4		ordnance; ship armor; gunpowder
Rubber	1	canteens; rubber pontoons	
Telegraph	1	Military telegraph	
Draftsman	1	Naval Engineer	
Services			
Ship captain	2	ships	ships; balloon-ship
River Clearing	1	gunboat	gunboat
Lawyer	1	waterproof cartridge	waterproof cartridge
Other			
Real Estate	1	Machine gun	machine gun
Aeronaut	1	observation balloon	
Farmer	1		rifle

Sources: Dictionary of American Biography (New York, 1937); *National Cyclopaedia of American Biography* (New York, 1898-); *A Biographical Dictionary of American Civil Engineers*, 2 vols. (New York, 1972 and 1991).

[a] I selected innovators alive during the war, numbering 321, from an extended list of 444 innovators surveyed for patents; some had no patents. Many of those without such wartime contributions invented or produced goods used in the war.

machine tools, shoemaking machines, hardware, condensed milk, and artificial legs. Established dynamics thus contributed directly to the war effort. Yet, 46 percent of war-related innovators invented or made military equipment for the first time. Generic machinists and others specializing in textiles, machine tools, and printing presses made firearms or firearms machinery. Other metalworkers formed ordnance and armor. Civil engineers moved into naval engineering and military invention. The universal knowledge such innovators possessed enabled the North to increase production with extraordinary rapidity. Machinists, engineers, and applied scientists were especially important; they made up four-fifths of military innovators, and related firearms and metalworking occupations made up half of the rest. The Confederacy had few such benefits; one of its military innovators had trained at West Point, and the other invented sewing machines manufactured by Brown and Sharpe, whose machine tools, ironically, equipped Union armories.

Small arms were central to the precipitous growth of military production. Army demands far exceeded the capacity of existing suppliers. The U.S. Army had destroyed the Harpers Ferry Armory, and the Springfield Armory could not approach the military's needs. Initially the Ordnance Department imported large quantities, including five-sixths of small arms purchased in the first year of the war. By 1862, domestic producers were the principal suppliers. The Springfield Armory increased output from 14,000 firearms in 1861 to a high of 276,000 in 1864, making about half of all Springfield rifles. Private domestic producers supplied nearly as many Springfield rifles and muskets, 400,000 breech-loaders for cavalry and other use, and 360,000 revolvers. Altogether, private domestic firms doubled the Armory's output over the course of the war.[4]

The government sought interchangeable firearms made to its patterns. Accomplishing this task was challenging, even when the government loosened its standards. For even the most advanced firearms firm, making new weapons created challenges. Colt manufactured over 100,000 Springfield muskets, but initial retooling was so great that it contracted out the work. Firms without experience making interchangeable-parts firearms had to learn. Some private firms succeeded quickly; by 1863, six had government purchases exceeding $500,000, some with no prior firearms experience.[5]

Three groups were responsible for the remarkable growth: the Ordnance Department and the Springfield Armory, the network of private firearms firms and skilled workers, and the broader community of machinists.

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[4] Imported firearms often were of lower quality and posed the problem of repairing distinct models. Such repair problems fell on the Springfield Armory, already charged with increasing its output and ensuring the quality of private contractors; ibid., 75, 231-32; Felicia Johnson Deyrup, *Arms Makers of the Connecticut Valley* (Smith College Studies in History, 33) (Northampton, Mass., 1948), 177-84; Carl L. Davis, *Arming the Union: Small Arms in the Civil War* (Port Washington, N.Y., 1973), 105.

[5] Wilson, *The Business of War*, 231.

Collectively, the groups updated the government-centered Armory system in a more advanced mechanical setting. The Ordnance Department let hundreds of firearms contracts over the war, inspected arms, and certified that contracts had been met. The Springfield Armory produced firearms, administered many private contracts, issued pattern arms to contractors, and worked with contractors to meet its standards, allowing them to use its equipment to make gauges. The Armory purchased machine tools from a wide variety of sources. Government engineers learned from firms; for example, Ordnance Department and Springfield Armory personnel visited William Sellers' machine-tool plant in 1861. In the 1830s, the Armory became a "pivotal clearinghouse for the acquisition and dissemination of technical know-how." It regained this position in the war as suppliers and contractors regularly turned to it for help.[6]

Without an active network of private firms with interchangeable-parts experience, the government's ambitious goal would have been virtually impossible to realize. The network involved firearms firms, mostly in New England, together with skilled workers, inventors, and suppliers. The most advanced firm was the largest contractor; Colt had government sales of $4.7 million over the course of the war, concentrated in the period when other firms were coming on line. Its Hartford competitor, Sharps Rifle, established for a decade, utilized Robbins and Lawrence workers to organize its production process. It was the second largest domestic contractor at the beginning of the war and the third largest overall. Another established producer, Remington, was the second largest domestic contractor over the course of the war.

Other firms well ensconced in the firearms network began production immediately before or during the war. Colt employee Christopher Spencer established a firm to make his repeating rifle, which had sales over $2 million during the second half of the war. Lamson, Goodnow, and Yale produced in the Robbins and Lawrence factory (the leading firearms firm of 1850), led by a Robbins and Lawrence machinist. Two other leading contractors had been firearms inventors in the 1850s. Many smaller contractors had similar origins, including the Whitney Armory.[7] The dynamics of the private firearms industry was a principal source of contractors with mass-production capabilities.

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[6] Merritt Roe Smith, "Eli Whitney and the American System of Manufacturing," in *Technology in America*, ed. Carroll W. Pursell (Cambridge, Mass., 1990), 45-61, quotation at p. 58; William Sellers & Co., "Visitors Register," 1861-1947, accession no. 1466, Hagley Museum and Library, Wilmington, Del.; Deyrup, *Arms Makers of the Connecticut Valley*, 177-204. On the difficulties of the Ordnance Department in purchasing, inspecting, and servicing arms, see Davis, *Arming the Union*.

[7] Wilson, *The Business of War*, 231; Joseph W. Roe, *English and American Tool Builders* (New Haven, Conn., 1916), 175-77, 192-93. U.S. House of Representatives, *Ordnance Department*, 40th Cong., 2d sess., 1868, series 1338, H. Executive Doc. 99; includes a list of firearms contractors with the federal government.

The broader machinery sector provided other sources of continuity. The supply of machine tools was a major barrier to rapid production growth. The Springfield Armory and some firearms firms had the capability to make their own machine tools, but even they relied on purchased machinery. The Armory bought machine tools from thirty-five firms. Except for Colt, the American Watch Company, and a few others, they were all machinery firms. George Lincoln, Pratt and Whitney, and some others had close links to the firearms industry, but most made machine tools, textile machinery, locomotives, engines, presses, woodworking machinery, and much more.

The firms included leaders in precision production, such as William Sellers, Bement and Dougherty, Richard Hoe, Brown and Sharpe, and the Lowell Machine Shop.[8] Generic design and production skills built up over the previous decade eased entry into firearms machinery. Firms entered quickly; in August 1861, the *Scientific American* reported that the production of firearms machinery was "calling into requisition the resources of all our first-class machine shops," including "nearly the entire works of Messrs. Bement & Dougherty."[9] Coordination problems slowed expansion, as new contractors acquired specifications and patterns and dealt with annoyances such as mismatched screw threads. In early 1862, Hoe, the leading printing-press manufacturer, wrote the Armory that "It is a matter of the greatest importance to us, that we have the patterns at once. We have lost much time already."[10] Learning grew with machine-tool sales; Sellers had visitors from firms making firearms and firearm machinery throughout the war. Firms even publicized their advances; in 1862, Brown and Sharpe advertised a machine "for turning and cutting the thread on the breech pin of the Springfield Rifled Musket."[11]

Machinery firms also contracted to make firearms. The Ordnance Department's list included Amoskeag and Mason (principally in textile machinery and locomotives); Parker, Snow, and Co. (hardware, engines, presses, pumps, and machine tools); and James Millholland (railroad equipment). The largest two, each totaling over $500,000 in contracts, were Alfred Jenks and Son and the Providence Tool Company. Jenks was one of the oldest textile-machinery firms in the country, and its Philadelphia location provided proximity to Bement and Sellers. It studied Springfield

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[8] Deyrup, *Arms Makers of the Connecticut Valley*, 194.
[9] "Machinery for Gun-Making," *Scientific American* 5 (24 Aug. 1861): 113.
[10] Richard M. Hoe and Company, *Records, 1824-1953*, box 24, letterbooks, 3 Feb.-9 July 1862, Columbia University Library, 201 and passim. Along with sixty rifling machines for the Springfield Armory, Hoe made rifling machines for a private armory, power-compressing machines for the Du Pont and Hazard powder companies, hydraulic presses to compress dry meat and vegetables, shaped shells for Parrott guns, and sheet metal for Monitor hulls and turrets. Frank E. Comparato, *Chronicles of Genius and Folly: R. Hoe & Company and the Printing Press as a Service to Democracy* (Culver City, Calif., 1979), 140-45.
[11] Advertisement in *Scientific American* (15 Nov. 1862), 319.

Armory techniques in designing its plant.[12] Providence Tool specialized in hardware and machinery such as cold-iron presses. From its initial forays into firearms, which it undertook "in a state of complete ignorance concerning the character of the work and the requirements of the Government," in two years it developed an advanced armory that made virtually every part of the rifle.[13] To its own metalworking expertise, it added the capabilities of others. Its superintendent, Frederick Howe, perhaps the most original of the Robbins and Lawrence machinists, had the highest level of capabilities and enjoyed extensive contacts. Partly through Howe's efforts, Providence Tool formed a close working relationship with Brown and Sharpe. It used Brown and Sharpe tapping machines to prepare the barrel for insertion of the breech pin, the turret screw machine for a great variety of parts, and the universal milling machine to make firearms machinery.[14]

Private armories increased output so rapidly because they held universal mechanical knowledge, often had mass-production experience, and acquired knowledge through the Ordnance Department, the Springfield Armory, suppliers, subcontractors, and the mobility of workers. Relations were not always cordial. Firms often failed to meet contracts and resented competitors' efforts to recruit their workers. The government argued with contractors, including R. Hoe, about costs and quality. Nevertheless, private deliveries of around 1.6 million arms greatly aided the war effort.[15]

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[12] Barton H. Jenks, *Papers,* Hagley Museum and Library, Wilmington, Del.; Deyrup, *Arms Makers of the Connecticut Valley,* 180. On earlier production by contractors, see 1860 manufacturing census manuscripts, and J. Leander Bishop, *A History of American Manufactures from 1608 to 1860*, 3 vols. (Philadelphia, Pa., 1868), 3: passim.

[13] "How A Rifled Musket Is Made at the Providence Tool Company's Armory," *Scientific American* (7 Nov. and 14 Nov. 1863), 293-94, 308-10, quotation at p. 293. The authors present a detailed description of the armory's techniques.

[14] Brown and Sharpe, *A Brown and Sharpe Catalogue Collection* (Mendham, N.J., 1997), 22, 29.

[15] Established capabilities and network contacts also sped the supply of other military equipment. The biggest suppliers of heavy ordnance were three venerable foundries with long connections to the military: Cyrus Alger in Boston, active since the War of 1812; Robert Parrott's West Point Foundry, which had made cannons since 1817; and Charles Knap's Pittsburgh foundry, which had cast government cannon since 1814. Each had a history of experimental ordnance work, and Parrott, a West Point graduate, had been a Captain of Ordnance. The Navy also depended on such continuities. Though Monitor-class vessels were new, the Navy had been investing in steam warships for fifteen years, and they continued to employ the same set of federal Navy Yards and private marine-engine builders and shipyards that had built and equipped ships before the war. There were changes, such as new Western Monitor builders, and some entrants, including Corliss, did not succeed in building marine engines. However, eastern and western firms used substantial engine and shipbuilding capabilities to multiply the number and modify the design of Navy ships. Wilson, *The Business of War*, 76, 232; Bishop, *A History of American*

Invention, too, took a warlike turn. Charles Porter noted, "The Civil war had just broken out, and every Yankee was making some warlike invention." Firearms inventions increased significantly; surveyed firearms patents grew by 77 percent from 1856-1860 to 1861-1865, when total patents grew by 22 percent.[16] By one estimate, the share of war-related patents tripled, though still amounting to only one-tenth of all patents.[17] The discontinuity in pace was accompanied by one of personnel; only one-fifth of inventors first patenting firearms during the war years came from firearms networks (principally firearms manufacturers and gunsmiths), well below the half share of the previous six years (see Table 2). If patenting could grow rapidly outside networks, how central were networks to technical change? Perhaps anyone could invent in response to surging demand.

We can reasonably interpret growing firearms patenting as a response to shifting potential markets. Although new inventors would have impacts later, including some Army and Ordnance Department officers, the basic wartime changes were well grounded in existing networks. Patenting growth continued a prewar trend that had increased firearms patents from 1856 through 1860 by 170 percent over the previous five years. Prewar network inventors were more likely to continue inventing during the war. They comprised 48 percent of all firearms inventors with known occupations during the period from 1855 to 1860, and 57 percent of those who continued inventing during the following five years.

Persistent network inventors averaged more patents than those outside networks, and far more than those who began after 1860. Indeed, they averaged almost three patents from 1861 through 1865, twice the average of inventors beginning during the war.[18] Almost half of the persistent inventors gained use, or at least the prospects of use, as principals in, or assignees to, firearms firms. Moreover, almost one-third of those beginning to invent during the war who gained use did so with firms operating before the war,

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Manufactures, passim. William H. Roberts, *Civil War Ironclads: the U.S. Navy and Industrial Mobilization* (Baltimore, Md., 2002).

[16] Charles T. Porter, *Engineering Reminiscences* (1908; rprt. Bradley, Ill., 1985), 28. For a description of the patent survey methods, see Thomson, *Structures of Change***,** chap. 3.

[17] B. Zorina Khan, "Creative Destruction: Technological Change and Resource Reallocation during the American Civil War," paper presented at the Economic History Association meeting, Toronto, Sept. 2005.

[18] That the twenty-eight persisting inventors had nearly as many Civil War inventions as the sixty-eight beginning after 1860 points to the importance of continuity. Data on inventors with occupations probably exaggerates the importance of network inventors, because those with no recorded occupation likely had lower network shares. On the other hand, some listed as non-network inventors actually had network links. For example, the city directory listing for Christopher Spencer, who had worked for Colt, was as a machinist. Machinists received one-quarter of firearms patents, yet because firearms were mechanisms with moving parts, most inventors had considerable mechanical knowledge.

TABLE 2
Firearms Patents and Networks, 1855-1865

	Inventors, Known Occupations (#)	Network Share (%)	Patents, Network Inventors	Patents, Non-network Inventors	Share with Use (%)	Patents, with Use
1855-1860 only	38	42.1	1.75	1.36	13.2	2.24
1855-1860 and Civil War	28	57.1	6.25	4.33	47.6	5.90
Only Civil War	68	20.6	1.43	1.35	9.9	1.59
All	134	34.3	3.22	1.76	15.0	3.24

Sources: U.S. Patent Office, *Subject Matter Index of Patents for Inventions Issued by the United States Patent Office from 1790 to 1873, Inclusive* (Washington, 1874). Occupations determined from city and business directories and manuscripts of the population census.

Notes: I ascertained occupations for one-third of all surveyed firearms inventors. The network share compares inventors in networks to all with known occupations. The share with use compares those with potential usage (as principals of firearms firms or assignees to these firms) to all inventors, not just those with occupations; twenty-two inventors with such usage did not have occupations revealed through city directories or census manuscripts.

much as successful firms in other industries used patents of new inventors.[19] As a further sign of continuity, outside the South, the regional distribution of patents before the war remained unchanged during the war, led by mid-Atlantic and New England regions. The urban share of patents remained at 57 percent.

Antebellum inventors undertook most of the significant advances in firearms. Breechloaders, repeaters, and metal ammunition were exceptions at the beginning of the war, but they were weapons of choice by the war's end. The Ordnance Department tested breechloaders in the 1850s, but initially opposed their usage in the war, and Springfield produced none. Private producers educated in firearms networks in the 1850s were the key innovators, including Sharps, Burnside, and Spencer. Army officers, especially those linked to the cavalry, purchased breechloaders, and the Ordnance Department finally endorsed them. The war probably accelerated the adoption of breechloaders for military purposes, but they were already ascending in civilian use.[20]

Firearms had led in interchangeable-parts mass-production metalworking for a half-century before the war, and continued to lead during the war. The Springfield Armory remained at the center of the learning, now supplemented by Colt and other private armories. Firearms firms, especially those long established, improved machining and forging techniques.

Inventors from several firms patented lathes and planers to manufacture firearms, and unpatented improvements greatly extended their contribution. Capital-goods firms ascended, including Pratt and Whitney, which built on its Colt training to sell mass-production machinery extensively. Brown and Sharpe was particularly important; its lathes, tapping machines, and, especially, its universal miller were significant innovations in metalworking with widespread ramifications. The needs of the Providence Tool armory, together with Brown and Sharpe's own sewing-machine production, occasioned the changes. The war sped diffusion. By 1867, universal miller purchasers included five leading private firearms firms, the Springfield Armory, a government arsenal, a government Navy Yard, an ammunition

[19] Assignments for new inventors were limited to those made at the time the patent was issued, because I consulted patent assignment records only for inventors who began by 1860. Other wartime inventors no doubt assigned patents after issuance.
[20] On the development of military arms, see Davis, *Arming the Union*. Heavy ordnance also developed through established private firms, though the Ordnance Department played a more innovative role. Naval armaments advanced through a complex interaction of private innovators, the Navy and its shipyards, and established private firms, as the ascendance of Monitor-type ironclads illustrates; see Roberts, *Civil War Ironclads*.

company, and three other machinery firms with wartime armories. The firm's screw machines had armaments markets just as wide.[21]

Antebellum firearms, ordnance, and shipbuilding networks, which integrated the government, private firms, and inventors, underpinned the great weaponry expansion of the Civil War. The machinery sector provided invaluable inputs, personnel, and manufacturers. Mechanical engineers advanced heavy ordnance and warships. Applied science contributed chemical companies making gunpowder and civil engineers laying out military railroads and military telegraphs. Technological centers were vital to Northern advantages. New firms and wartime innovators contributed, but they learned from leading industries and centers. In its magnitude and length, the Civil War marked a great discontinuity, but capabilities established over the previous quarter-century enabled the North to increase and modify war output rapidly, whereas the South could not. Without the contrasting capabilities, the war would have lengthened, and its outcome might have changed.

Mechanizing Shoemaking

At the same time the firearms industry flourished, mechanization came to shoe bottoming, fostered by spillovers from other sectors. Mechanization brought the factory to a putting-out industry. The transformation, well under way when the war began, rested on continuities with prior mechanization and patenting. Supported by New England textile, sewing, and woodworking networks, innovators had challenged the two basic parts of the putting-out system, which made uppers and then united uppers with soles.

Mechanization initially applied the dry-thread sewing machine to light leather. John Nichols adapted one of the first Singer machines to shoe uppers, and then designed shoe sewing machines for Singer and for Grover and Baker. Major sewing machine firms dominated the market. A more fundamental change mechanized waxed-thread stitching on heavier uppers. William Wickersham solved the problem of sewing with waxed threads by using an awl, a hooked needle, and a looper to form a chain stitch. Part of the eastern Massachusetts machinery community, Wickersham made machines and instruments in Lowell, where Howe and other sewing machine inventors had labored. Professionally linked to invention, Wickersham advertised that he would "give his personal attention to the construction of Models for Patent Machinery of all kinds, and to the repairing of optical instruments."[22] Well-attuned to local machinery improvements, he invented cloth-pressing irons and filtering devices at the same time as he mechanized leather sewing. The Boston-area machinists William Butterfield and Edgar Stevens built and sold his machine. Threatened with patent litigation, Wickersham assigned rights

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[21] Brown and Sharpe, *A Brown and Sharpe Catalogue Collection*. Production improvements affected heavier machinery as well, notably rolling improvements used on ironclads.

[22] *The Lowell Directory* (Lowell, 1851), advertisements, 10.

to Elmer Townsend, who used this patent and those of three other inventors to make a machine that, by 1860, diffused throughout the regional shoe industry.[23]

The transformation of shoe bottoming began with pegging. The invention of pegging machines occurred as early as 1829, but real progress did not occur until the mid-1850s. Elmer Townsend, the key entrepreneur, proceeded through patent purchase, beginning with John Greenough's 1854 invention. Greenough had worked as a machinist for the Patent Office, patented a sewing machine in 1842, invented woodworking equipment, became a patent agent, and published a respected mechanics' journal. He put this extraordinary background to work in designing his pegging machine, which had the shape and feed of a sewing machine and formed its own wood pegs. Townsend bought patents from five other machinists or professional inventors, but succeeded only when he purchased rights from Benjamin Sturtevant. A Maine shoemaker who became a Boston machinist, Sturtevant first assigned Townsend a lasting tool and, later, five more patents. He did not assign his most important invention, a design for a ribbon of peg wood cut from the circumference of a log and a lathe to make it; instead, he sold peg strips himself.[24]

Machine-using shoemakers, machinists searching for profitable products, and the patent system combined to lead to the first practical bottom-sewing machine. The central innovator, Lyman Blake, was a Massachusetts shoemaker experienced in upper-sewing machines. He distributed Singer machines and trained others to use them before forming an upper-sewing shop. Pondering the problem of bottom-sewing, he developed, and in 1858 patented, a machine to stitch through the upper and soles using a rotating hook to feed thread on the inside of the shoe. His shoe design emulated the pegged shoe and departed from the hand-sewn shoe, which stitched the upper to an inner sole and welt in one seam and the welt to the outer sole in another. Recognizing that he lacked the capabilities to produce and sell the machine, Blake turned to patent assignment. Three competitors vied for the

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[23] Ross Thomson, *The Path to Mechanized Shoe Production in the United States* (Chapel Hill, N.C., 1989), 119-22. For Wickersham's assignments, see U.S. Patent Office, "Patent Assignment Digests," vol. W-1, 258, 285, 287; vol. W-2, passim, National Archives, College Park, Md.

[24] Thomson, *The Path to Mechanized Shoe Production*. For Townsend's assignments, see "Patent Assignment Digests;" vol. B-1, 220, 233, 242; G-1, 233, 279; R-1, 216; S-1, 308, 311, 313; S-2, 3, 12, 29, 90, 122, 139, 149, 165, 183; W-1, 259, 259. On litigation, see Charles H. McDermott, *A History of the Shoe and Leather Industries of the United States* (Boston, Mass., 1918), 64-68. On early mechanization, see Blanche Hazard, *The Organization of the Boot and Shoe Industry in Massachusetts before 1875* (Cambridge, Mass., 1921).

patent rights, and Blake sold his rights to Gordon McKay for a down payment of $8,000 and the promise to pay $62,000 more.[25]

McKay was one of a host of emergent machinist-entrepreneurs. Trained as a civil engineer, he worked on railroads and the Erie Canal. Around 1845, he set up a Pittsfield, Massachusetts, machine shop to repair textile and paper machines, and began patenting with a steam engine. In 1852, he became the general manager of the Lawrence Machine Shop, which built textile and a great variety of other machinery, including his engine. Lawrence used McKay's engine to run machinery at the New York Crystal Palace Exhibition in 1853. McKay invented two printing presses, which Lawrence manufactured. On the lookout for opportunities, he investigated shoemaking, having witnessed one pegging-machine patent. Through a Boston patent agent, he learned of Blake's patent and others' efforts to buy it. Recognizing its potential, he entered the market and won the competition with Edgar Stevens and other New England machinists.[26]

McKay knew he needed to develop the invention and, along with Blake and hired inventors, set out to do so. The Civil War was a hard time for the shoe industry; Boston shipments fell by one-third from 1860 to 1861 and did not recover until 1865. However, the war advanced McKay's cause. He secured federal contracts for soldiers' footwear; through 1862, he made 150,000 pairs. The revenue helped; McKay reported royalties of almost $100,000 in 1864. Wartime sales allowed McKay to improve the machine. In applying to renew his patent, Blake noted that army contracts were "undertaken with a view to test the machine, that it might be rendered as perfect as possible before it was sold to the public." Though the Army rejected some of the shoes, revenues enabled McKay to develop the machine. McKay received six shoe-sewing patents and five related shoemaking patents from 1862 to 1865, six jointly with Blake. Blake received four other patents, and two hired inventors improved the machine.[27] Emulating sewing machine firms, McKay set up company sales agencies. To overcome problems of high fixed costs for small manufacturers, he leased the machine, rather than selling it. Along with military contracts, he developed the machine to make women's shoes. Fostered by army sales of over 470,000 pairs, the machine was poised to penetrate the civilian market soon after the war.[28]

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[25] Thomson, *The Path to Mechanized Shoe Production*, 156-165; for assignments see "Patent Assignment Digests," vol. B-2, 105, 106, 168, 171, 173, 212, 214.

[26] Ibid; *Official Catalogue of the New York Exhibition of the Industry of All Nations, 1853*, 1st ed. rev. (New York, 1853), 37.

[27] Quoted from Lyman Blake, *Application of Lyman Blake for Extension of Letters Patent* (Boston, 1874), 7, 9, and 25; Thomson, *The Path to Mechanized Shoe Production*, 161, 163, and 181. Royalties from machine usage increased from $38,800 in 1863, to $99,200 in 1864, and to $150,800 in 1865, some with army contracts and others with civilian markets; see *Shoe and Leather Reporter* 17 (30 July 1874): 1.

[28] Grace Rogers Cooper, *The Invention of the Sewing Machine* (Washington, D.C., 1968), 60. McKay army sales might have been greater. The army purchased

Shoemaking invention extended to lasting, other bottoming operations, soles and heels, upper cutting, and various tools and work-support devices. It showed remarkable continuity over the decade from 1856 through 1865. The number of wartime shoe patents (including shoe-sewing machines) just about equaled that of the previous five years. Network inventors—shoemakers, shoe machinists, and shoe merchants—comprised 56 percent of inventors with known occupations and received 62 percent of patents during the period (see Table 3).[29] Between those who invented only before the war, and those who continued inventing during the war, they made up almost half of prewar inventors and received a little over half of all antebellum patents. Network inventors were more important during the war; they comprised 62 percent of Civil War inventors, and received 72 percent of patents. They were especially important among those beginning to invent during the war. Persisting inventors also manifested continuity. Twelve percent of inventors patented before and during the war, but they were especially prolific, with 30 percent of all patents, 62 percent issued to network inventors.[30] The patent system also supplied continuity; eight wartime inventors without earlier shoe patents had other prewar patents, including two sewing machine inventors and Gordon McKay. [31]

Inventors from technological occupations—overwhelmingly machinists—comprised 36 percent of inventors over the whole period; they were more prolific, with 2.2 shoe patents compared to 1.4 for other inventors, and they received 47 percent of all shoe patents. Thirty percent were network inventors, though others clearly had links to the industry. They received almost half of all the patents issued to such occupations. Technological occupations were especially important among antebellum patentees who

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approximately 8 million pairs of shoes from 1861 through 1864, and the 470,000 pairs were about 6 percent of the total. One McKay user, Seth Bryant, claimed to have made 200,000 to 300,000 pairs; his recorded contracts of $364,000 suggest that he was closer to the lower estimate. Many others also made machine-sewn shoes; see Seth Bryant, *Shoe and Leather Trade of the Last Hundred Years* (Boston, 1891), 37, 77, and 112; Wilson, *The Business of War*, 233.

[29] The network share was higher yet, as indicated by the fact that another seven inventors, with twelve patents in the period, assigned patents to shoe machinery firms at the time of patent issuance. Patent assignment was common; one-half of thirty-nine inventors researched assigned at least one shoe patent to others at or after patent issuance, including nearly two-thirds of machinists, inventors, and applied scientists. Thomson, *Structures of Change,* chap. 10.

[30] Continuing inventors were somewhat more common; three other inventors, with seven wartime patents, patented shoe improvements before 1856, but none in the years from 1856 to 1860.

[31] Patenting inside and outside shoemaking was common; about 36 percent of inventors crossed over. They averaged 3.3 non-shoe patents and 2.7 shoe patents through 1865. On crossover invention over a longer period, see Ross Thomson, "Crossover Inventors and Technological Linkages: American Shoemaking and the Broader Economy, 1848-1901," *Technology and Culture* 32 (Oct. 1991): 1018-46.

TABLE 3
Shoe Inventors by Occupation and Patent Type

	Inventors, Known Occupations (#)	Patents per Inventor	Inventors, Network Share (%)	Patents, Network Inventors	Patents, Non-network Inventors	Patents, Network Share (%)
All						
All	125	1.73	56.0	1.90	1.51	61.6
Technological Occupations	45	2.24	31.1	3.50	1.68	48.5
Other Occupations	80	1.44	70.0	1.50	1.29	73.0
1856-1860 only						
All	65	1.20	50.8	1.18	1.22	50.0
Technological Occupations	22	1.36	27.3	1.67	1.25	33.3
Other Occupations	43	1.12	62.8	1.07	1.19	60.4
1856-1860 and Civil War						
All	15	4.33	46.7	5.71	3.13	61.5
Technological Occupations	11	4.27	45.5	5.20	3.50	55.3
Other Occupations	4	4.50	50.0	7.00	2.00	77.8
Civil War Only						
All	45	1.62	66.7	1.80	1.27	74.0
Technological Occupations	12	2.00	25.0	4.33	1.22	54.2
Other Occupations	33	1.48	81.8	1.52	1.33	83.7

Note: Percentages are row percentages; for example, network inventors comprised 56 percent of the 125 inventors with known occupations.

continued to invent during the war, making up almost three-quarters of such inventors with the same proportion of patents.

Machinists and other technological occupations were particularly important for complex machines. They comprised 62 percent of sewing and pegging machine inventors. Many had training in related industries. John Bradshaw was a textile machinist who received the first improvement patent on Howe's sewing machine before turning to pegging machines. At least seven inventors had been trained in sewing machine firms; four of them first patented sewing machines. Technological occupations made up only 28 percent of inventors for other operations; shoemakers and a few lastmakers and toolmakers were far more important in developing shoe designs, manufacturing processes, and tools. In addition, machinists' design and production skills supported all invention. Being part of Eastern technological communities helped in the manufacture of machines; McKay and a pegging-machine firm bought Brown and Sharpe's universal milling machines by the mid-1860s.

Shoemaking networks centered around Massachusetts, where the shoe industry and shoe invention had long been concentrated. Mechanization modified knowledge in shoemakers' networks, so that artisans such as Blake learned mechanical techniques. Massachusetts inventors received 56 percent of shoemaking patents after 1855, and the same share before and during the war. The prospect of forming machinery firms and assigning patents encouraged shoemakers and machinists to invent. By the 1850s, Massachusetts investors were seeking out profitable inventions, and patent assignment was common. Townsend bought thirty-five sewing, pegging, and other shoemaking patents from fourteen inventors.

As an industry already mass producing for national markets, shoemaking clearly had a potential demand for machinery. Networks and centers helped realize the potential before the war, and the same institutions operated throughout the war. Formed around machinery firms and factory users, networks sustained and extended mechanization. Inventors from textile and apparel sectors utilized convergent technologies that spread readily in eastern New England. An earlier spillover from firearms was essential; without the pattern lathe to make standard shoe lasts, bottoming machinery could not have made standard sizes.[32] Broader groups of machinists contributed to invention and machine production. Patent agents relayed information to potential entrants. Military contracts for machine-made sewn and pegged shoes simply accelerated a mechanization process already under way.

New Resources: Petroleum

The petroleum industry drew on a wide range of capabilities for its quick success. The great discovery of Edwin Drake's 1859 Titusville well was a much-trumpeted qualitative break, but its significance, and perhaps its very

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[32] Thomson, *The Path to Mechanized Shoe Production*, 42-44.

existence, derived from the actions of pharmaceutical and chemical firms, leading academic chemists, salt producers, pump-makers, lamp-makers, and many others. Petroleum even found ready-made networks among coal oil producers. Drake's accomplishment in an underdeveloped part of Pennsylvania depended from the start on Eastern urban capabilities. The industry's ascent, begun before the war, continued throughout the conflict, though the wartime economy helped little and perhaps even slowed it.

To succeed, the petroleum industry required adequate reserves and potential demand, but also techniques to pump, store, transport, distill, and use oil. By the 1850s, petroleum had three potential markets. It was widely used for medical purposes, most commonly as a liniment. Heavier oils found use as lubricants. Illumination had the biggest potential; petroleum could be used to replace whale oil, lard oil, camphene, coal-based illuminating gas, and coal oil.[33] The illumination market was well established; in 1860 lamps, fixtures, and illuminants employed nearly one percent of the manufacturing labor force with twice as much value added, led by illuminating gas.

Petroleum production drew on several established techniques. Drilling techniques had developed in salt wells, especially in Kanasha County, West Virginia. From 1806, producers developed methods to drill through rock to depths of 1,500 feet and pump up brine. The original wooden tubing was replaced by tin, and then by copper. By the 1830s, steam engines drove the pumps; in 1838, small engines, most made in Pittsburgh, ran sixty-one wells. The flatboat, steamboat, and railroad could move oil; the steam revolution hence played roles in both production and transportation. Tanks and barrels to store petroleum were common.[34] Domestic industries molded sheet brass, pressed glass, and adapted lamps of European design to use camphene and, from 1850, coal oil and petroleum. Pittsburgh and other cities in the trans-Allegheny West were centers of steam and metalworking capabilities.

The most complex task refined crude oil into usable products. Although no one understood the chemistry of petroleum until long after it came into use, other illuminants and lubricants provided a model. Isaiah Jennings, the versatile machinist-inventor of the Jennings rifle and steam engines, patented the first synthetic illuminant, camphene. In seventeen illumination and chemical patents from 1829 through 1850, Jennings developed not only methods to distill camphene from turpentine, but also lamps to burn it. From the 1830s, the production of illuminating gas involved a simple process that

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[33] Harold F. Williamson and Arnold R. Daum, *The American Petroleum Industry: The Age of Illumination, 1859-1899* (Evanston, Ill., 1959), 12-42.

[34] Paul H. Giddens, *The Early Petroleum Industry* (Philadelphia, Pa., 1974), 1-6; Williamson and Daum, *The American Petroleum Industry*, 12-24; U.S. Treasury Department, *Steam-Engine*, 25th Cong., 3d sess., 1839, H. Doc. 21, serial 345, pp. 226-29. The drilling of salt wells provides another example of the independent origins of early inventions. It was largely the product of a wood-based society utilizing craft techniques. Yet, its further development relied on the steam engine and metal piping and drilling equipment.

heated coal and purified the resulting gases; other localities used natural gas to the same end. Improved techniques and large-scale urban production spread gas illumination, including a $1 million investment in Philadelphia.

Europeans pioneered the manufacture of coal oil, mostly for lubrication. The American coal oil industry, begun in the mid-1850s, provided central underpinnings to the petroleum industry. Coal oil was a byproduct of efforts to produce illuminating gas and lubricants. Abraham Gesner received seven patents for coal oil, which he called kerosene, and set up a New York firm to manufacture and distribute it. More important was a Boston firm formed by pharmaceutical manufacturers and a sperm-oil producer to make lubricating oil from coal tar, utilizing a process Luther Atwood patented in 1853. While introducing the technique in Scotland, Atwood and another company employee, Joshua Merrill, discovered a way make an excellent illuminant from coal-tar naphthas. Their firm turned to illuminants, and, using thirteen more patents by Atwood, seven by Merrill, and patent licenses from a British inventor, they learned to produce, distill, and purify coal oil. They also developed cracking and refining methods to increase yields and improve quality. American sulfuric acid manufacturers supplied needed inputs. By 1858, kerosene was a commercial success, cheaper than sperm oil and safer than camphene. New York and Boston led, with Pittsburgh following. Some firms applied refining techniques to petroleum, but the modest petroleum supply prevented it from competing with coal oil.[35]

The process that introduced petroleum as a key resource began in 1851, when a Dartmouth-trained doctor, Francis Brewer, joined a lumber firm in Titusville, Pennsylvania. Having used petroleum as a medicine, he was intrigued by local oil gathered from the surface of springs. Without science, his efforts would have come to nothing. Brewer had a petroleum sample analyzed at Dartmouth, where a chemist encouraged him and put him in touch with a future partner. A campus visit by a Dartmouth alumnus began a process that led to the formation of the Pennsylvania Rock Oil Company in 1855, to buy land and develop petroleum. Luther Atwood and the eminent Yale chemistry professor Benjamin Silliman, Jr. submitted favorable reports. The Silliman report, which has been called "perhaps the most epochal report in petroleum history," synthesized knowledge of petroleum, raised the possibility of changing its molecular structure at high heat, and—most important for the company—estimated that at least half of the crude could be transformed into illuminants.

Producers learned from other industries. By 1861, major coal oil firms were applying their techniques to refine petroleum. Drillers migrated from salt-well regions. Steamboats and railroads transported oil. Coal oil lamps

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[35] Williamson and Daum, *The American Petroleum Industry*, 27-60; Christopher J. Castaneda, *Invisible Fuel: Manufactured and Natural Gas in America, 1800-2000* (New York, 1999), 13-44. Jennings' patents were surveyed in the study of crossover steam-engine inventors; a study of petroleum patents included those of Atwood and Merrill. Philadelphia gaslight investment data are from the 1850 census manuscripts.

were adapted to burn petroleum. New wells, including the first gushers, rapid growth of refining capacity, and falling prices signaled the permanence of the industry. In 1860, petroleum output reached coal oil's 200,000 barrels; in 1862 petroleum's 3 million barrels dwarfed coal oil output. The war slowed market growth when Southern sales stopped; they formed almost one-third of the domestic market for illuminants before the war. Despite the tax imposed on petroleum illuminants, refined petroleum surged to 335,000 barrels in 1862, and then quadrupled through 1865.[36]

Initial petroleum production was quite backward. Titusville was located in a timber and farming area distant from railroads. The Pennsylvania Rock Oil Company hired E. L. Drake, a railroad conductor, to supervise its affairs. Who decided to drill for oil is unclear, but Drake hired a salt driller to bore a well. Drilling was slower than in salt wells; animals powered some efforts. Teamsters transported the oil, and new refiners were small and primitive.

From drilling to final use, all aspects of petroleum production would change, and those changes were well under way by the war's end. Improved drilling methods included casing to prevent flooding and superior pump design. Portable steam engines powered drills and pumps; horsepower grew as wells deepened. Gas replaced wood and coal as a fuel. Transmitting power to the drill became more effective. Torpedoing used gunpowder and then nitroglycerin to open wells clogged by paraffin. Watertight barrels and tanks improved storage. Floating methods, copied from lumber, moved oil to the Allegheny River. Pipelines, well known in urban water and gas systems, brought oil to rivers and railroads beginning in 1865. By then, railroads, some with tank cars, had moved into regional towns.[37]

Applied scientists improved refining methods. The advances, though proceeding with little recognition of concurrent discoveries in organic chemistry, employed chemical knowledge of specific gravities, boiling points of petroleum fractions, and Silliman's observations on fractional distillation and cracking. Merrill and Atwood quickly adapted the techniques of coal oil refiners to petroleum. Sugar refining also contributed. Petroleum refiners adopted existing terminology, measures, testing procedures, and distillation methods, but required further changes. Instrument makers developed temperature- and ignition-testing devices for distilling. Refiners improved distillation and cracking techniques and developed methods for purifying distilled petroleum. The petroleum industry generated adequate products so quickly because it drew on techniques and personnel from other sectors.[38]

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[36] Williamson and Daum, *The American Petroleum Industry*, 63-112, 118, 290, 309-11, 737, quotation at p. 69. Interestingly, Silliman's father, Benjamin, Sr., had published one of the first reports on American petroleum in 1833. Both were heavily involved in geology, as were many chemists who worked in geological surveys and in firms assessing the quality of minerals.

[37] Ibid, 136-89.

[38] Ibid, 206-27.

Few of the initial capabilities came from the oil area itself, though it did develop and even export skills in drilling, transportation, and storage. The wider region supplied critical capabilities. Pittsburgh already produced coal oil and became the regional center for the petroleum industry. Its 1861 city directory listed eleven oil merchants (both "coal and carbon"), four oil-pump and salt-tube manufacturers, three oil-tool manufacturers, and one oil-barrel factory. Refineries grew for coal oil and petroleum. Firms offered "pure white burning oil" and lubricants, some together with lamps. In 1863, the directory listed forty dealers selling crude and refined oil, twenty-two refiners, three oil brokers, three oil-tank manufacturers, one barrel manufacturer, one barrel dealer, and one shipper, who stored and forwarded oil. In addition, brass founders, coppersmiths, and sheet-iron producers offered to equip and repair refineries, and engine and boiler firms sold power and refining equipment.[39]

Firms from other regions contributed. Most important were the New York and Boston refineries, which led in distilling improvements. The major coal oil firms all moved into petroleum, led by Boston's Downer Kerosene Oil Company, which Joshua Merrill superintended. It led in cracking technology, and licensed some of its key cracking and treating patents to the New York Kerosene Company and to others. Downer established a refinery and depot in Corry Pennsylvania, where the Erie Railroad met railroads to the oil fields, to which it brought eastern coopers, mechanics, tank builders, and refiners.[40] John and Giuseppe Tagliabue developed devices to measure specific gravity, product uniformity, and explosiveness. They had long been leading New York instrument-makers; Giuseppe had made and invented thermometers, barometers, hydrometers, and other instruments used by the Coastal Survey and by firms making alcohol, sugar, foods, and other products. The Utica-based Wood and Mann Steam Engine company targeted its portable steam engine at well drillers, who would not need to erect fixed engine rooms. Its engine already ran circular saws, wood-planers, stone cutters, tanneries, churns, and threshers, and was readily adapted to drill and pump. So important was the petroleum market that the firm set up an agency in Titusville, and sold not only engines, but also "oil well outfits complete." Its catalog included nine Titusville references and an equal number from other petroleum areas.[41]

Patenting patterns demonstrate how petroleum methods benefited from wider knowledge. Over 100 patentees improved petroleum production (mostly wells and storage) and refining (including coal oil improvements that applied to petroleum). They received almost 200 petroleum patents and another 70 for related coal-gas, oil-lamp, pumping, drilling, and measurement inventions. Altogether 72 percent of inventors had technological

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[39] Pittsburgh city directories, 1861-1862, 354 and 33, advertisements; 1863-1864, 383 and 48-57, advertisements; 1864-1865, 366 and 57-77, advertisements.

[40] Williamson and Daum, *The American Petroleum Industry,* 175-79, 190, and 219-45; Bishop, *A History of American Manufactures,* 310-12.

[41] *The Wood and Mann Steam Engine Company, Builders of Their Celebrated Patent Portable Steam Engines* (Utica, N.Y, 1866), 5.

occupations, and they had 85 percent of petroleum patents (see Table 4). Well over half of the inventors had scientific or inventive occupations. Almost one-third were chemists who distilled petroleum and coal oil, or made soap, pharmaceuticals, and glue. One-fifth were engineers and patent agents. Inventors from scientific and inventive operations received four-fifths of refining patents and one-half of drilling and other production patents. Machinists, less common than in most innovations, concentrated on the mechanical sides of the industry, especially drilling and related operations. Other manufacturers had a modest patent share, but were important for testing devices. Only a quarter of inventors had jobs in petroleum networks, but they received over two-fifths of all oil patents and three-fifths of refining patents. Applied scientists, supplemented by machinists and instrument-makers, were essential to petroleum use and invention.

Petroleum patents grew dramatically. Even including coal oil patents, only 20 percent of the pre-1866 patents were issued through 1860. Patents grew especially late in the war, with 11 percent in 1864 and fully 50 percent in 1865, foreshadowing things to come. This growth came with substantial continuity. Inventors' occupations remained much the same. Over 70 percent of inventors held technological occupations before and after the war, with 85 percent of petroleum patents in each period. Network inventors comprised 50 percent of antebellum patentees, with 62 percent of antebellum patents. Their share of patents fell to 35 percent during the war, in part because wider ranges of inventors addressed petroleum production, including instrument-makers developing measurement devices, valve-makers designing pumps, and chemists developing oil paints and lamps. About one-tenth of inventors patented petroleum improvements before and during the war, and they received one-fifth of wartime petroleum patents.

Inventors learned from earlier patenting. Four-fifths invented prior to the first petroleum patent. One-third of those inventors patented in related areas. Several developed gas and oil techniques. Others had chemical patents, or invented pumps, steam-measuring devices, rock drills, water wells, and thermometers. Such related patents offered an avenue to petroleum invention for those outside petroleum networks. Altogether, 30 percent of wartime inventors, with the same share of wartime patents, had petroleum-related patents before the war.

Location of invention also reflected continuity. Throughout the period, invention was national in scope. Despite the localization of petroleum extraction in a few counties in northwest Pennsylvania, only seven inventors located in that area, and they concentrated almost entirely on drilling. Inventors in cities with over 10,000 population received almost three-quarters of petroleum patents. They were especially important in refining, with four-fifths of patents, but urban inventors also received two-thirds of

TABLE 4
Petroleum Patentees by Occupation

	Inventors, Known Occupations (#)	Average Oil Patents	Average Related Patents	Inventors, Network Share (%)	Patents, Network Inventors	Patents, Network Share (%)	Related, Network Share (%)
All							
All	53	2.36	1.09	24.5	4.08	42.4	20.7
Technological Occupations	38	2.79	1.16	34.2	4.08	50.%	27.3
Other Occupations	15	1.27	0.93	0.0			
Prewar only							
All	9	1.56	1.11	22.2	1.00	14.3	40.0
Technological Occupations	6	1.50	1.33	33.3	1.00	22.2	50.0
Other Occupations	3	1.67	0.67	0.0			
Prewar and Civil War							
All	5	7.00	0.60	100.0	7.00	100.0	100.0
Technological Occupations	5	7.00	0.60	100.0	7.00	100.0	100.0
Other Occupations	0						
Civil War Only							
All	39	1.95	1.15	15.4	2.67	21.1	11.1
Technological Occupations	27	2.30	1.22	22.2	2.67	25.8	15.2
Other Occupations	12	1.17	1.00	0.0		0.0	0.0

Sources: U.S. Patent Office, *Subject Matter Index of Patents for Inventions Issued by the United States Patent Office from 1790 to 1873, Inclusive* (Washington, D.C., 1874); *Annual Reports of the Commissioner of Patents*, 1847-1865.

Notes: Occupations could be determined for 53 patentees: half of all petroleum inventors, with 64 percent of petroleum patents. Petroleum patents here include petroleum and coal oil drilling, pumping, storing, and distilling inventions. Related patents include those for coal gas, lamps, steam pumps and gauges, chemical transformations, and drilling.

drilling and related extraction patents. The urban share of patents remained about the same throughout the period. The regional share changed little; inventors in the Mid-Atlantic states received four-fifths of patents before and during the war. Rural western Pennsylvania developed petroleum production so fast because other industries and regions supplied critical knowledge.

Unlike shoemaking, which involved learning from a few spatially contiguous sectors, petroleum entailed learning from many disparate, dispersed industries. Academic and industrial chemists played a prominent role, from Silliman's studies of petroleum through chemists improving refining and using explosives in drilling. Although a follower in academic and industrial chemistry, the United States was able to provide inputs such as sulfuric acid and the knowledge needed to innovate in coal- and petroleum-based chemicals.

With organic chemistry in its infancy, innovations largely concerned mechanical design and physical control of production.[42] Coal-based gas and oil industries were leaders. Drilling techniques spilled over from salt making. A long line of pump improvers set the stage for petroleum pumping and piping; the Worthington pump would become an industry standard. Engines and transportation were already at hand. Eastern brass workers developed lamps that burned whale oil, camphene, coal oil, and then petroleum. Machinists designed and made refining machinery and occasionally opened refineries. Patents and scientific assessments supplied conditions for forming corporations, and the wide licensing of some core patents, especially those of Luther Atwood and the British inventor James Young, eased entry into refining. Paul David and Gavin Wright have argued that American resource abundance rested on having the resources and being able to utilize them.[43] In the case of petroleum, many prior technological changes and each technological center enabled rapid resource use.

Simultaneity and Integration

How did innovators respond to the economic dislocations of the Civil War? The dislocations were relatively large, including the loss of almost a third of the domestic market for illuminants, roughly the same decline in Boston shoe shipments, but a huge increase in firearms output. Military needs substantially reduced the civilian labor supply, including network practitioners and technological occupations that could contribute to innovation. How did innovations in firearms, petroleum, and shoemaking develop and succeed in these conditions?

Continuity with prewar patterns supplied much of the answer. Each innovation originated before the war, including new types of firearms, shoe bottom-sewing machines, and petroleum extraction and production. In each,

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[42] William Haynes, *American Chemical Industry*, vol. 1: *Background and Beginnings: 1609-1911* (New York, 1954), 249.

[43] Paul David and Gavin Wright, "Increasing Returns and the Genesis of American Resource Abundance," *Industrial and Corporate Change* 6 (March 1997): 203-45.

innovation continued along lines already in motion. The location of patenting remained much the same. Industrial networks were central to invention in each case. It is true that in petroleum and firearms (but not in shoemaking) the network share of patents declined for those first inventing during the war. Much of the decrease in petroleum resulted from the entry of inventors in technologically related occupations. In each sector, antebellum inventors continued patenting in the war, receiving from one-fifth to one-third of wartime patents.

Each innovation benefited from technological occupations before and during the war. Applied scientists, engineers, machinists, drafters, and patent agents, all of whom held universal knowledge relevant to many industries, dominated invention in petroleum and sophisticated shoe machines, but had the lowest share in firearms, where firearms manufacturers had considerable technological prowess. Technological occupations were especially important in applying convergent technology to innovations, enabling innovations to succeed far faster than industry capabilities would have allowed. Firearms drew in major machinery and hardware firms. Shoemaking benefited from textile machinists such as Gordon McKay and from sewing machine inventors before and during the war. Petroleum utilized capabilities from coal oil, salt drilling, instrument making, and lamp making. Each innovation purchased machine tools and other metalworking equipment. The broad capabilities of technological occupations offered flexibility to the economy that enabled innovations to begin and mature quickly, using knowledge developed in other industries.

In the face of this continuity, what impact did the dislocations of war have? The war clearly accelerated firearms production, both in established products such as the Springfield rifle and in the newer breechloaders and repeaters. It also accelerated firearms inventions, some of which came to fruition after the war. It spread interchangeable-parts metalworking methods, and fostered the development of machine-tool firms, both of which had effects on other sectors following the war. In spite of declining shoe sales, the war stimulated shoe mechanization through the experimentation that government contracts financed, which sped the improvement of McKay machines. The loss of Southern markets, if anything, slowed petroleum innovation.

It is important to note what the war did not do. Falling demand did not inhibit innovations in any fundamental way. Both McKay shoes and petroleum grew by substituting for other products, and both found new markets in the government or from exports. Even the declining civilian labor force did little to impair growth. Shoe firms experienced labor scarcity, which may have fostered mechanization. The war-induced scarcity of technologically proficient labor may have been a bigger problem, yet there is no evidence that this shortage impaired incipient innovations. In part, labor transferred from some established industries, including textiles and textile machinery, a sector paralyzed by the war. Generally, the United States had established a scale of capabilities sufficient to allow innovation on many fronts.

Invention in some sectors did decline; clock and woodworking patents during 1861-1865 did not reach half of the totals of the previous five years, and several other technologies fell modestly. However, patenting in others rose, including firearms, machine tools, shoe machines, petroleum, and, less expected, textiles and engines. Widespread invention in part reflected the modest resource demands of even so destructive a war, when army shoe purchases were about 7 percent of Northern production, and war-related patents were only 10 percent of the total.[44] More fundamentally, the pattern manifested a density of innovational capabilities sufficient to allow considerable redeployment without thwarting new initiatives and progress in developing older ones.

Indeed, innovation in many sectors grew during the war. The economy multiplied military production, penetrated markets of earlier innovations, and dedicated resources to new, largely civilian innovations that often drew on the same inventive resources. Mass-production firearms multiplied at the same time as interchangeable parts sewing machines and watches originated; each continued processes begun before the war. Mass-production watches developed during the 1850s, when Aaron Dennison, a watch repairer who studied interchangeable parts methods on visits to the Springfield Armory, designed "an interchangeable system" to manufacture "in large quantities" and formed the Waltham Watch Company (later the American Watch Company) to achieve this objective. In 1860, the firm employed 200 workers to make about 15,000 watches, worth $245,000. Stimulated by new models for soldiers, industrial innovation by Ambrose Webster, who had trained at the Springfield Armory, and machine-tool purchases from Brown and Sharpe, output increased to 45,000 in 1865.[45]

The sewing machine was the most important recipient of interchangeable parts production, and firearms played a causal role in the two most advanced cases, which both started before the war. Brown and Sharpe mass produced the Willcox and Gibbs sewing machine, stimulated by its connection with Frederick Howe, who superintended the Providence Tool Company and prompted Brown's machine-tool invention. Wheeler and Wilson also imported armory methods beginning in 1858, relying on the capabilities of William Perry, a Colt

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44 Patent data from the technology samples developed in Thomson, *Structures of Change,* chaps. 3, 5, 6, and 8. For total Civil War shoe output, see Thomson, *The Path to Mechanized Shoe Production,* 181.

45 Charles W. Moore, *Timing A Century: History of the Waltham Watch Company* (Cambridge, Mass., 1945), 6-69, 230-31, quotations at p. 13; Henry G. Abbott, *History of the American Waltham Watch Company of Waltham Mass.* (Chicago, 1905); Donald R. Hoke, *Ingenious Yankees: The Rise of the American System of Manufactures in the Private Sector* (New York, 1990), 180-205. For a contemporary account of the plant, see "The Factory of the American Watch Company," *Scientific American* (11 April 1863), 225-27.

contractor who became superintendent of its Bridgeport factory, and two Robbins and Lawrence contractors.[46] Although they called on the same resources, each innovation path added to innovative capabilities. What is more, the various innovations supported one another. Joseph Brown's turret-lathe, developed to make firearms and sewing machines, became a central mass production machine tool. His universal milling machine gained even wider usage.[47] After learning mass-production techniques from working with firearms, the American Watch company sold equipment to the Springfield Armory, and sewing machine firms made firearms parts.

Had military demands been substantially greater, so would have been the effects on innovation. Yet innovation still would have depended on the prior development of networks and centers. The South experienced considerably greater economic dislocation, but, with thin technological capabilities, achieved little innovative success. The same factors that enabled internal dynamics to continue in the North made them difficult to start in the South. That Northern innovation in the war was so widespread resulted less from any effect of the war than from capabilities and agents formed in peacetime and the processes they maintained when peace had been shattered.

[46] "Wheeler and Wilson's Sewing Machine Manufactory," *Scientific American* (3 Jan. 1863), 1-3; David Hounshell, *From the American System to Mass Production*, 1800-1932: *Development of Manufacturing Technology in the United States* (Baltimore, Md., 1984), 68-75; Thomson, *The Path to Mechanized Shoe Production*, 141. The *Scientific American* recognized that interchangeability was incomplete when it wrote that "It is remark-able also, to see a machine shop where no files are used; we mean by this, none in comparison to what are generally consumed" (p. 3).

[47] "Wheeler and Wilson's Sewing Machine Manufactory"; Roe, *English and American Tool Builders,* 207-11; Brown and Sharpe Manufacturing Company, Records, 1833-1994 , Rhode Island Historical Society, Providence.