*"The American System of Manufactures: Factor Bias or the Democratization of Invention?"**

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Abstract

Imbued with the scientific rationality of the Enlightenment in the period prior to the Civil War Americans actively embraced the use of interchangeable parts and machine tools in manufacturing. Imbued with the Enlightenment concept of equality of opportunity the political architects of the young republic fostered the democratization of invention through the creation of an accessible patent system and the promotion of basic education and universal literacy. The result was a high rate of augmentation of all factors of production, of capital, labor and land. After the Civil War the rates of augmentation interacted with scale economies, accelerating total factor productivity growth. The resulting overall productivity growth was not induced by the relative supplies of land, labor and capital. In particular it did not have a labor-saving bias.

"The Congress shall have the Power …. to promote the Progress of Science and useful Arts, by securing for limited Times to Authors and Inventors the exclusive Right to their respective Writings and Discoveries" (Article I, Section 8, Clause 8) of the Constitution

"Congress shall make no law …. abridging the freedom of speech, or of the press …" (Amendment I of the Constitution)

"Equality suggests to the human mind several ideas that would not have originated from any other source .... I take as an ex ample the idea of human perfectibility.... In proportion as castes disappear and the classes of society draw together...the image of an ideal but always fugitive perfection presents itself to the human mind....I accost an American sailor and I enquire why the ships are built so as to last for only a short time, he answers without hesitation that the art of navigation is every day making such rapid progress that the finest vessel would become almost useless if it lasted beyond a few years."

Alexis de Tocqueville, *Democracy in America*, Volume II, Chapter VIII "How Equality Suggests to the Americans the Idea of the Indefinite Perfectibility of Man"

I Interchangeable Parts and Machine Tools: The American System of Manufactures as a General Purpose Technology

The career of Thomas Jefferson beautifully illustrates the contradictory tendencies in the Enlightenment program.

Born in the agrarian elite of Virginia in the mid-18th century, he studied Latin, Greek, and French as a boy, entering the College of William & Mary at age 16, poring over the writings of John Locke, Francis Bacon and Isaac Newton. A polymath, he learned to play the violin and steeped himself in a wide range of fields, ranging from the classics, philosophy, metaphysics and mathematics. Heir to an estate of 5,000 acres and numerous slaves, Jefferson spent lavishly on creating a stunning mansion at Monticello that he personally designed along neoclassical lines. At Monticello he exercised his inventiveness, designing mechanically driven furniture, an ascending bed, automatic folding doors, a wine-bottle elevator connecting his wine collection in the cellar to his dining room. In short Jefferson shared with the Enlightenment elites of Europe a fascination with scientific rationality and invention embodying scientific reasoning in practical engineering applications.

As Minister to France between 1785 and 1789, Jefferson deepened his knowledge of French and British advances in the practical application of science. In 1785, in Paris, he visited the workshop of Honoré Blanc, a military blacksmith working in an experimental workshop. Blanc's mission was developing a novel method of turning out muskets in a standardized fashion. Enjoying the support of the French artillery service, Blanc was assembling flintlock mechanisms, drawing components – tumblers, cocks, screws, and springs – out of bins each devoted to one component. What impressed Jefferson was the principle of modular assembly: creating large volumes of interchangeable parts that later on would be fit together, reducing costs through scientifically informed engineering while simultaneously enforcing product standards. On his return to the United States, Jefferson shipped a bundle of gunlocks to his newly founded nation; upon his arrival in his homeland he became a fervent advocate for the employ of interchangeable parts in the manufacture of small arms. Indeed soon after Jefferson's return to his country, the army's Ordinance Department underwrote the application of Blanc's principles in its Springfield and Harpers Ferry arsenals.[1] Visiting England during his assignment to France, Jefferson visited a steam driven flour milling factory, the engine's tremendous potential for generating inanimate energy making an equally compelling impression. Indeed he envisioned the application of steam power to locomotion, a vision that was soon realized with the rapid spread of steam railroads in the antebellum United States.[2] In sum, Jefferson hoped the United States would be the beneficiary of a scientific rationalism that was largely the product of intellectual elites in Europe.

At the same time Jefferson was committed to the political principles of the Enlightenment as Americans understood the message of classical British liberalism: individual liberty, equality and the spread of democracy as a political system best designed to protect the natural human right to "life, liberty and the pursuit of happiness." In his political agenda Jefferson took the position that the best way to fashion a republic founded on Enlightenment ideals was by fostering local democratic decision making by an informed, literate, populace of family farmers. Yet as a member of the Southern elite Jefferson benefited from coerced slave labor at Monticello and he wished to draw upon the cornucopia of inventions largely ushering out of the ranks British and French elites. True – as Mokyr (2002, 2009) reminds us – the Industrial Enlightenment in Great Britain bubbled out of a knowledge cauldron in which theories put forward by elite philosophers and scientists mixed with the practical experience non-elite mechanics. Still, elites played a disproportionate role in promoting the Enlightenment ideal.

How could these two tendencies – the potential elitism of scientific rationality and the egalitarian democratic agenda – be best reconciled? The answer that Jefferson and his colleagues who drafted the American Constitution arrived at was the democratization of invention. In practice this meant placing in the Constitution a Congressional mandate to create and maintain an accessible patent system providing short-term private property rights for technical breakthroughs. And it meant guaranteeing widespread public access to knowledge of state-of-art technology through freedom of the press, basic literacy, and minimal copyright protection for the authors of books and articles appearing in newspapers, technical journals and magazines publishing information about technical advances for mass audiences. [3]

In short, Jefferson's Jason-faced attraction to the scientific technological implications of the Enlightenment and to the egalitarian ideals underpinning political philosophy of the Enlightenment was realized in the writing of the American Constitution: Article 1, Section 8, Clause 8 requires Congress to establish and maintain a patent system; and the First Amendment to the Constitution guarantees freedom of speech and the press. That the group of political elites who actually drafted the wording of the Constitution, and that it was ratified by State conventions, is testimony to the broad acceptance of these principles within the informed body politic of the late 19th century United States.

The thesis of this paper is that Jefferson's approach to reconciling the imperative of promoting widespread diffusion of scientific rationality in the form of cost-reducing inventions with the egalitarian ideal of equality of opportunity as realized in the basic institutional blueprint for the United States promoted high rates of factor augmentation in 19th century. Land was augmented; capital was augmented; and so was labor. This was especially important in creating and diffusing a general purpose technology throughout the antebellum United States, the American System of Manufactures.[4]

I characterize augmentation for each of the factors of production as follows: land is augmented through fertilization, irrigation, and selection and/or hybridization of seed varieties and domesticated animals used in farming; capital is improved through the embodying of technical advances in its construction; and labor is augmented by increases in hours worked and/or improvements in the efficiency of each hour worked.[5] Using formal algebra I define augmented land as:

[1] $$La^* = (q_{La})\, La$$

where **La*** is augmented land, q_{La} is land quality (taking into account biological inventions and enrichment through irrigation and fertilization embodied in it), and **La** is land area (in acres). Again, I define augmented capital as:

[2] $$K^* = (q_K)K$$

where **K*** is augmented capital, q_K is capital quality (the proxy I envision here is the average age of capital, its vintage), and **K** is the capital stock. Finally I define augmented labor **L*** as:

[3] $$L^* = h\, e(h)\, W$$

Where **L*** is augmented labor, **h** represents average hours worked per worker, e(h) is the efficiency of each hour worked, and **W** represents the number of workers.

With these augmented factors of production I write a simple multiplicative Cobb-Douglas production function:

$$[4] \quad \mathbf{Q = A\,(K^*)^{\alpha}(L^*)^{\beta}(La^*)^{[1-(\alpha+\beta)]}}$$

where A is the index of total factor productivity and the exponents for each augmented factor of production are the shares of the augmented factor in total income. Reconfiguring the equation in terms of growth rates for A and for each augmented factor or production yields the following equation for growth rates - the growth rate of each variable **x** is **g(x)** – relating growth in output to growth in total factor productivity and growth in the augmented factors of production, namely:

$$[5] \quad \mathbf{g(Q) = g(A) + \alpha\, g(K^*) + \beta\, g(L^*) + [1-(\alpha+\beta)]\, g(La^*)}$$

This is the equation that will guide our discussion through the remainder of this paper.

To return to my argument concerning the sources of productivity growth in the 19th century United States I argue that the major contributions to it were: (a) augmentation of the factors of production was relatively high because of the democratization of invention embodied in the Constitution; (b) augmentation of each factor of production was complementary with augmentation in the other factors of production; (c) in manufacturing the American system of manufactures exemplified by the combination of growing reliance on machine tools and interchangeable parts was the main source of augmentation (the growing reliance was attributable to convergence of invention on the supply side and the nature of demand in far-flung isolated Western communities on the demand side); (d) in agriculture the geographic march of the country into new climates and soils in the West induced augmentation of land; and (e) the growth in total factor productivity accelerated particularly after the Civil War due to scale economies and organizational changes induced by carrying on production and distribution over a vast territory; and (f) the process of productivity growth throughout the 19th century did not exhibit a factor bias, in particular it was not labor-saving.

To illustrate the argument graphically consider Figure 1 **[Figure 1 about here]**. The key point is that the inward shift in total factor productivity takes place across the entire range of factor endowments. The standard argument that technological progress in the 19th century United States exhibited a pronounced factor bias envisions inward shifts in the region around A in the diagram (that is on the capital/land intensive end of the technology spectrum). This is induced by a high ratio of wages relative to the rental price on land ($\mathbf{w/r_{La}}$). One of the key arguments of this paper is that the biased technological thesis is incorrect.

II The Factor Bias Thesis: Two Objections

The argument that 19th century American technological change was biased is often made. Indeed, in teaching classes on North American Economic History this author has made it, more than occasionally and with considerable emphasis.[6] The idea that the nature of technological change reflects relative factor supplies comes naturally to economists looking for materialistic explanations for inward shift of the technology frontier; the idea that the inward shift is induced by factor supplies allows one to tell a simple story without relying on exogenous institutional factors like the incentives to invent created in the United States Constitution. Unfortunately, as appealing as it the factor bias story is, it is plain wrong.

There are many variants of the thesis. The most famous version is due to Habakkuk (1962) [7] The basic idea is simple: the existence of undeveloped agricultural land – land not yet cleared of trees and rocks but land that has the potential for productive uses in farming – bid up the price of unskilled labor in the United States encouraging manufacturers to substitute capital for workers. To this observation Habakkuk added a second point: there was almost no elasticity to the supply of unskilled labor in the United States: increasing employment of unskilled workers bids up manufacturing wages rapidly. Knowing this managers and owners of factories searched for labor-saving inventions, searched in all directions, ultimately embracing machine tools and interchangeable parts as a way to cut down on unskilled workers. Knowing this American farmers mechanized at a relatively early date, earlier than their British counterparts who enjoyed more favourable terms of trade for their farming produce (because machinery prices were dropping relative to the prices for foodstuffs during most of the years between 1790 and 1940). The American economy became heavily mechanized at an early point – despite being primarily agricultural – precisely because unskilled labor was relative expensive and supplied with a very low elasticity. Despite being agrarian throughout most of the 19th century the United States economy was shaped – its technological progress guided – by a bias toward using capital and saving labor, substituting the former for the latter.

Consider Figure 2 which illustrates a rather extreme – but not implausible – version of the hypothesis. **[Figure 2 about here]**. There are two kind of potential workers: those who - other things equal - prefer to farm; and those who aspire to be professionals or who would rather labor in factories acquiring skills through job experience rather than pursue agriculture.

The former either take up farming as young adults or take up factory employment in order to save, gathering in their hands resources sufficient to secure an established farm or sufficient to purchase land and improve it by clearing it of rocks and trees. The prospective farmers are basically unskilled since they are reluctant to invest in training that will pay off in future factory employment. This gives rise to a backward bending supply curve for unskilled labor: when the demand for unskilled labor expands in the industrial sector, wages soaring, ultimately reducing the supply of labor available (because it takes less time to build up a nest egg required for access into agriculture). The frontier - an elastic supply of relatively cheap land that can be improved – promotes the substitution of capital for unskilled labor.

This is the essence of the Habakkuk hypothesis: in the United States unskilled labor is relatively expensive and inelastically supplied to manufacturing. Likewise to farmers who have difficulty obtaining assistance during the planting, ploughing and harvesting seasons. Manufactures embrace capital intensive techniques; so do farmers. The result is capital intensive mechanization, the incentive to invent labor-saving machinery being especially strong. In contrast skilled labor is relatively cheap and elastically – compared to unskilled labor – since not everyone wants to be a farmer.

Pursuing this logic Habakkuk argues that in Western Europe, especially in industrializing Great Britain, the opposite holds. Frontier land being unavailable, unskilled labor is abundant and relatively cheap and – excepting in times of warfare – elastically supplied to manufactures. Hence technological progress tends to take place on the labor-using, capital saving end of the spectrum.[8] Since there is a bias in manufacturing technological progress toward the capital intensive end of the sprectrum – potential improvements to labor-saving machinery outstripping potential improvements to labor-using machinery – technological progress in the United States eventually outpaces that achieved in Great Britain despite Great Britain's initial advantage in industrial activities.

In terms of Figure 1 the Habakkuk thesis is that American technological progress occurs in the range of the point A; technological progress in Western Europe, in Great Britain in particular, in the range of point B.

The figures in Table 1 bear on this point. As can be seen the ratio of the wages for engineers to the wages paid general laborers is approximately identical in Great Britain and the United States. **[Table 1 about here].** So it is not at all clear whether Habakkuk's assumption that skilled labor is relatively inexpensive in the United States is valid. [9]

Moreover Habakkuk has to concede that his assumption that unskilled labor was inelastically supplied in the United States throughout the entire 19th century only holds for a few early decades of the 19th century. Indeed he admits that improvements in transportation stemming from the growing use of steam power in shipping and in railroads reduced barriers to trans-Atlantic migration. As can be seen from Table 2 the immigration – and the net immigration – rate picked up in the 1840s and remained relatively high throughout the remainder of the century. **[Table 2 about here].** Moreover the birth rate was far higher during the first half of the 19th century in the United States than it was in Great Britain (or for that matter in the remainder of Western Europe). The result was greater population growth in America than in the old world, the United States population outstripping that of the United

Kingdom by mid-century. As well it is apparent from Table 3 the United States had far more railroad track than did the United Kingdom (or France) by the 1840s. **[Table 3 about here]**. So even new cities springing up on the frontier of the United States were being linked together in the web of a rapidly expanding railroad network; labor was being elastically supplied because the American birth rate was high; because immigration was picking up; and because railroad track mileage was being built at a phenomenal rate.

That labor market evidence does not give unambiguous support to the Habakkuk thesis is by no means the sole objection to its validity. In a standard dualistic economy agriculture mainly relies on inputs of land and labor; manufacturing mainly uses capital and labor. If wages in the United States are relatively high, so is the cost of machinery. The only way around this conclusion lies in the borrowing cost of capital, in the nature of the technologies in the two countries, or in assumptions regarding the type of labor utilized in American manufacturing. Regarding the borrowing cost of capital in the first half of the 19th century there is considerable evidence that interest rates were higher in the United States than in Great Britain. [10] Basing his reasoning on this point Field (1983) argues that capital intensity was actually greater in the United Kingdom than it was in the United States during most of the 19th century. Field bolsters this argument by noting that American machinery was generally flimsier than British machinery. Boilers wore out faster; steam engines depreciated faster. British machinery was designed to last; American machinery, embodying less capital, fell into disrepair much more rapidly. [11]

To the argument about flimsy capital one can add two other points. British machinery – for instance machine tools like lathes and milling machines – was supplied to firms along specific lines. The client establishment got the machinery delivered that it wanted. On the other hand in the United States machinery was standardized; clients had to modify it at their own expense for their particular needs. [12] A classic example is the kit prepared for "patent reapers" marketed to American farmers by the company founded by Cyrus McCormick [13] The purchaser was expected to assemble the reaper using directions supplied with the components. A certain amount of "do-it-yourself" initiative on the part of customers purchasing machinery was assumed in the United States; apparently not so in Great Britain.

But even if we grant that American capital was short-lived, it does not follow that it was inferior. Consider the augmentation of American machinery through continual improvement, through an ongoing stream of inventions that was continually improving its quality. American machinery was being augmented at far higher rates than British machinery: it was on average younger in vintage, hence superior in terms of embodying the latest advances.

The same arguments apply to labor and land: both were being augmented at higher rates in the United States than they were in Western Europe throughout the 19th century. This is a key finding of a thorough study of biological innovation in American agriculture published by Olmstead and Rhode (2008). As can be seen from Table 4 the evidence assembled by Olmstead and Rhode calls into question a number of arguments advanced in favor of a high wage/cheap land interpretation of 19th century American technological progress. **[Table 4 about here].** According to Panel A of the table the relative price of land actually rises relative to wages throughout the so-called frontier period in American history (the frontier presumably disappearing around 1900). According to Panel B the pace of biological innovation was extremely rapid through the 19th century; according to Panel D much of this innovation was spurred by the spread of American farming westward into climes that were not hospitable to the seed varieties developed in the early 19th century. According to Panel C the tractor diffused rather late in the history of American agriculture, contradicting the thesis that adopting machinery was the principal, the most characteristic story about American farming. Indeed as far as the use of the tractor is concerned, Olmstead and Rhode note that the main consequence of its diffusion was saving on land (not labor), acreage for pasturing horses and mules being converted into crop land during the 20th century.

In short land augmentation – through biological innovation, through the development of hardier seed varieties, through the spread of irrigation infrastructure in the West (see Panel F in Table 4) – was the central fact about American productivity increase in the 19th century. One reason why this innovation was so rapid was the Red Queen principal that Olmstead and Rhode make central to their analysis: to stay still one has to run faster. As they note monoculture agriculture creates biological bite-back: the proliferation of plant diseases and pests. For example the Hessian fly, the midge, the clinch bug and rusts and bunt in the case of wheat; and the bollworm, cotton worm, boil weevil, wilts and seeding diseases in the case of cotton. Biological innovation was induced by the spread of crops to the West into dry farming territory and cold climes; biological innovation was induced by the Red Queen. All of this was part and parcel of land augmentation.

Moreover the combination of crop spread to westward latitudes and the logic of the Red Queen principle actually induced augmentation of labor, forcing up hours of work. For instance Olmstead and Rhode (2008: pg. 203) point out that according to a US Department of Agriculture survey in 1910-14, labor requirements varied tremendously between crops: tobacco (356 hours per acre), cotton (116 hours per acre), corn (35.2 hours per acre) and wheat (15.2 hours per acre). With the push westward more and more acreage went into crops that required higher – not lower – hourly work requirements than the ones they replaced. To which one can add the Red Queen problem, time required to hoe and weed fields expanding as the Red Queen issue intensified in the plains of the Midwest and the West.

In short in the most important sector of the American economy through most of the 19th century augmentation of land and augmentation of labor, not labor-saving, was the main story, mechanization being of secondary importance. As intuitively plausible as the factor-bias story is – the idea that American technological progress was induced by relative factor prices and/or elasticities of supply for the factors of production – the real story of the United States, particularly in the period prior to the Civil War, is augmentation of the factors of production primarily driven by expectations about the rate of invention and innovation. But this conclusion begs a second question: why was the expected rate of innovation improving on the factors of production so high?

III The American System of Manufactures: Human Development, the Patent System, "Do-it-Yourself" and Convergence in Invention 1790 – 1860

To produce standardized interchangeable parts two things are required: gauges to check on the accuracy of the components; and machine tools that can be set up to repetitively reproduce the required component without error. To do so with a high level of precision requires a very accurate machine tool. To do so on a mass production basis – reducing unit costs for each part manufactured – requires a machine tool that can rapidly generate a continuous flow of parts. During the period from 1790 to 1860 there was on-going improvement in machine tool design and the production of gauges, capital being augmented through invention in both the United States and Great Britain, especially in the United States. What was the secret of the American success in the deeply intertwined fields of machine tool design and the use of interchangeable parts?

In addressing this question it is useful to consider both the supply and the demand for inventions that augmented capital, not only machinery but also capital utilized in transportation and in building construction.

On the supply side six factors dominate: (1) the level of the human development index; (2) the patent system; (3) Federal and local state government support for projects; (4) a pool of advances in machinery production and application developed in Western Europe, primarily in Great Britain; (5) the “do-it-yourself” approach to marketing standardized products with interchangeable parts; and (6) the convergence of inventive activity in seemingly unrelated fields – textiles, railroads, firearms, woodworking, printing, shoe production – arising from the American System focus on machine tools and interchangeable parts.

On the demand side there are two considerations that seem especially important: (1) the geographical expansion of the United States out to the West and the Red Queen principle; and (2) the drive to cut unit production costs through the use of the American System of

Manufactures, laying the foundation for mass marketing and total factor productivity expansion during the second half of the 19th century.

As the reader may not be aware of the broad range of mechanical functions offered by machine tools it is useful to begin with a brief discussion of their salient features. As Floud (1976: pp. 20-23) points out the golden era of machine tool innovation took place in the first half of the 19th century, primarily in the United Kingdom and the United States.[14] One of the oldest machine tools, its progeny dating back to antiquity, is the lathe. With the lathe cutting is done with a static cutting tool operating on a revolving work-piece. The drilling machine performs its function with a drill held in a spindle that is rotated and inserted into a work-piece. The planning machine has a static cutting tool against which the work-piece is fed in a reciprocating action. In the shaping machine the work-piece is static against which a rotating cutting tool is drawn in a straight line. One of the most versatile machine tools is the milling machine that houses a multiple toothed rotating cutter. The grinding machine employs a abrasive wheel capable of stripping off small pieces of metal from worked on metal surfaces. Shearing and pressing machines rely on a guillotine motion to cut or form metal. Multiple cutters perform their work on sawing machines. Finally, the gear-cutting machine that combines milling and shaping functions is considered one of the most sophisticated tools in the family of machine tools.

As Floud (1976: pg. 23) nicely says the basic design of and principles of usage for machine tools was largely achieved by the middle of the 19th through “hundreds of minor modifications.” In short, continual augmentation through hundreds and hundreds of minor improvements was the key to machine tool development between the Napoleonic Wars and the American Civil War.

As the crucible of the industrial revolution, Great Britain had a natural lead in the development of machine tools. After all, they were being use to build steam engines. After all, the iron and steel industry had made leaps and bounds in the late 19th and early 20th centuries, steel products being spun off into railroads, bridges, and military hardware. But by the time the Crystal Palace Exhibition occurred at Hyde Park in the London of 1851 things had changed. Impressed with Colts pistols and the McCormick reaper and other products displayed by the Americans, the British press dropped its contemptuous attitude toward the products flowing out of Great Britain's former colonial possession: the country bumpkins had mastered small arms manufacturing; the American patent system once ridiculed by the British elites had seemingly generated a greater inventive bounty than Great Britain's long established patent system had. Why did the United States outstrip the British?

The first thing to note is that Americans in general were better fed, lived longer lives, and were better educated than the average individual in the United Kingdom. This fact comes through in Panel C of Table 2. True British elites probably outstripped American elites in sophistication. But at the level of the common person Americans were better off. Being more literate than were more likely to be aware of advances in technical knowledge; living longer lives they had greater incentive to invent and innovate, the pay-off period to their investment in gaining empirical knowledge stretching off further into the future. Being more physically robust Americans were more likely to work protracted hours. [15]

The second reason is the patent system. That Americans put great weight on placing in the Constitution a passage mandating a patent system is a strong embrace of Enlightenment principles. True in Europe, England and France were the most enlightened societies and England in particular had enjoyed a patent system since the early 1600s (codified in the Statue of Monopolies of 1624). And at the time of the French Revolution – in 1791 to be precise – the French abandoned the melange of pensions, bounties, subsidies and titles designed to encourage invention in favour of a patent system guaranteeing the natural right of inventors to enjoy property rights in patents. But unlike the United States which – after 1793 – demanded a minimal fee of $30 to register a patent, fees charged in Great Britain and France were far higher relative to average per capita income. [16] Not only were patents cheaper to secure in the United States, hence more open to the common person, after the reform of 1836 that created a Patent Office staffed by technically trained evaluators, the quality of the patent review process improved considerably. This gave great credibility to the validity of American patents.

There is considerable evidence supporting the notion of democratization of invention in the 19th century United States, particularly in the period before the Civil War. There was a decided shift toward non-elites, the role by merchants/professionals diminishing in the early 19th century; there was a rising share of patents with few patents over their inventive careers; and a low specialization among patentees.[17] Table 4 that compares patent granting in the United States and England bears on this point. **[Table 5 about here]** Adopting the pragmatic philosophy that American patent law was guaranteeing private property rights in intellectual capital for a limited duration Americans were more prone than their British counterparts to assign their patents to other individuals or enterprises, thereby raising capital to tide themselves over while they pursued other inventive ideas. [18] Moreover females participated actively in the patent system. [19]

A third factor was active participation by the Federal government, notably at the Springfield and Harpers Ferry arsenals. Working at Springfield, Eli Whitney developed – or at least engaged in a promotional campaign on behalf of - a milling machine. Later the Blanchard lathe was created at the two military equipment establishments, specifically designed to turn out gunstocks.[20] In the 1820s and 1830s, pursuing the goal of a complete set of interchangeable parts for small arms manufacture John Hall created special purpose milling equipment and drop-forging machinery for production of the percussion carbine. Not only did advance in machine tool manufacture aimed at reducing the costs of, and improving the quality of, pistols and carbines create positive spinoffs for other sectors (for example the Blanchard lathe was adopted by the woodworking sector). Because American military academies graduating more engineers than the government could employ in the armories, federal engineers were seconded, assigned to help build railroads.[21]

A fourth factor was taking opportunity of British and European advances, importing and adapting machines produced abroad. This was particularly true in the case of textiles – the water frame, power looms, and mules being brought over from England – and in engines (Watt steam engines) but was also true in locomotive manufacture and design.

The "do-it-yourself" marketing approach of companies like the McCormick Reaper Company was important. Customers could modify the kits that they received by inventing additional attachments using standardized parts. As a result inventiveness spread into rural communities.

But most important was the existence of convergence in inventing, stemming from the fact that the American System of Manufactures was a general purpose technology that spread from firearm production to engine manufacture, to clock making, to woodworking, to civil engineering, to the sewing machine, and to shoe machinery production. At work in all of these seemingly unrelated fields was the underlying principle of utilizing – and improving on – machine tools capable of turning out interchangeable parts. It was less the impetus from above – from government managed armories – and more the impetus from below that led to remarkable convergence in inventing in antebellum America. For instance a valuable summary table in Thomson (2009: pg. 213) shows that in the production of clocks, the layout of railroads, the design of telegraph equipment, the manufacture of harvesters and binders, the design of sewing machines (that played a major role in promoting mass production in the post-Civil War era), and the spawning of speciality machine tools like the turret lathe it was the push from below that caused the American System of Manufactures to blossom the way it did.

Demand was also important. On the frontier farms were isolated from one another. Farmers wanted small arms to ward off marauders, to kill bear and other animals. The wanted interchangeable parts so they could repair their own firearms. For instance in remote California saw mills in the 1850s superintendents demanded circular saws with inserted teeth because they preferred to replace teeth from stocks they held in supply rather than order or repair old saw blades.[22]

Equally important on the demand side was the challenge posed by the Red Queen. As agriculture moved out to the West, as pests and diseases attacked crops, farmers looked to any and every fix possible, including machinery that simplified hoeing and weeding.

Because French military engineers pioneered manufacturing using interchangeable parts it is useful to conclude this section by asking the question: why did France fail to advance the principle of modularity through assembly of standardized interchangeable parts as aggressively as did the Americans? The fact that they did not, even in the field of military hardware, is clear from the following quote from a report filed by Benedict Crowell, the United States Assistant Secretary of War, Director of Munitions in 1919 [23]:

> "Nor do the French know the American quality-production methods. The French artisan sees always the finished article, and he is given discretion in the final dimensions of parts and in the fitting and assembling of them. But the American mechanic sees only the part in which he is a specialist in machining, working with strict tolerances and producing pieces which require little or no fitting in the assembling room. Consequently, in the translating of French plans it was necessary to put into them what they had before, namely rigid tolerances and exact measurements."

The answer is not hard to find. Consider Table 6. **[Table 6 about here]**. As can be seen in a society populated by peasants, many who could neither speak or read French, patent activity and invention remained largely in the hands of the elite. Only with the penetration of railroads into remote rural areas – in the 1880s and 1890s – did change begin to sweep across the lives of the common person. [24] Even so, as late as the 1960s peasant agriculture still played an important role in French agriculture.

Democracy, literacy, access to opportunity for non-elites was crucial to American success in invention during the seven decades leading up to the Civil War.

IV From the American System of Manufactures to Mass Production: Total Factor Productivity Growth 1865-1900

In the second half of the 19th the American System of Manufactures gradually evolved into mass production. Increasingly productivity growth – in the half century before largely attributable to augmentation of the factors of production – took the form of total factor productivity growth.

Because I am arguing that inventive activity embodied in, augmenting land or capital, is not total factor productivity growth it is important to clarify the meaning of total factor productivity growth.

By total factor productivity growth I mean: (1) economies of scale and scope; (2) disembodied technical change associated with the evolution of knowledge, especially scientific knowledge (e.g.: the diffusion of knowledge of electricity and magnetism that revolutionized thinking about communications in the second half of the 19th century from the scientific community down to the level of the general populace); and (3) organizational changes that improve the efficiency with which the factors of production are combined.

In principle economies of scale are either internal or external to individual firms and factories. External scale economies include geographic scale economies, for instance concentration of banks, factories, professional services in urban conurbations. As the size of a handful of American cities reached levels of over a million persons – New York and Chicago are prime examples – scale economies are generated. Underlying the creation of massive central cites was the growth in American population. Tables 2 and 3 speak to this point. By 1870 American population and American national income outstripped the comparable magnitudes for the United Kingdom and France. The American market was reaching humungous size.

Economies of scope do not just arise from tapping into distribution networks like the railroad and the postal system. Ingenious marketing schemes innovate marketing. For instance Corliss who developed a variable cut-off mechanism for stationary steam engines offered to market the engines on the basis of savings in thermal efficiency. Again the Singer Sewing Machine Company drummed up business by aggressively selling to church groups and by offering rent-to-own options.

Undoubtedly being dramatic economies of scale internalized by firms get pride of place in discussions of scale economies. Especially notable was the development of the assembly line/conveyor belt system with its origin in the packing houses of Cincinnati in the 1860s. [25] Soon afterwards, companies like the Singer Sewing Machine company and the McCormick enterprise – enjoying massive expansion in sales – adopted lock, stock and barrel interchangeable parts. As volumes increased it became cost effective to invest in machine tools that cranked out standardized parts on a low unit cost basis. In this way production costs per sewing machine or per reaper, hence price per unit, dropped dramatically, driving out competitors from the market. Table 7 documents the volume increases for Singer and McCormick. **[Table 7 about here].** [26]

Disembodied organizational changes adopted by companies also played a role in promoting total factor productivity increase. Think of the Lowell system in textiles; the creation of multi-divisional companies; the development of large scale equity markets handling masses of buying and selling orders; the scientific management principles of Taylorism; and the spread of knowledge about basic principles of applied science and patent activity in journals like *Scientific American* and the *Journal of the Franklin Institute*.

In sum the evolution of the American System of Manufactures into Mass Production turned the United States into a major source – arguably in the 19th century the leading source – of inventive activity worldwide. This is illustrated with the figures in Table 8. **[Table 8 about here]**. [27] The democratization of invention had reaped a tremendous bounty indeed. One has the feeling that Thomas Jefferson would have been pleased.

IV Conclusions

Imbued with the scientific rationality of the Enlightenment in the period prior to the Civil War Americans actively embraced the use of interchangeable parts and machine tools in manufacturing. Imbued with the Enlightenment concept of equality of opportunity the political architects of the young republic fostered the democratization of invention through the creation of an accessible patent system and the promotion of basic education and universal literacy. The result was a high rate of augmentation of all factors of production, of capital, labor and land. After the Civil War the rates of augmentation interacted with scale economies, accelerating total factor productivity growth. The resulting overall productivity growth was not induced by the relative supplies of land, labor and capital. In particular it did not have a labor-saving bias.

Footnotes

[1] For advances in French arms production see Alder (1997). For accounts of the evolution of small arms production at Harpers Ferry see Smith (1977).

[2] See the figures in Panel B of Table 3.

[3] See Kahn (2005) and Sokoloff and Kahn (1994).

[4] By a general purpose technology is meant a technology that has general applicability, exhibits technological dynamism, and fosters "innovative complementarities" encouraging downstream users to carry on the innovative process by improving on the already existing techniques. See page 65 in Rosenberg and Trajtenberg (2004).

[5] See Chapter 2 in Mosk (2010).

[6] A thesis closely related to the factor bias theory for the 19th century United States is the Hayami-Ruttan thesis concerning mechanization of agriculture. The idea is that technological progress in farming in regions where wages are low relative to land rents (i.e.: the ratio $\mathbf{w/r_{la}}$ is low) – for instance in Japan, China and the Netherlands through the 19th and early 20th

centuries - should be labor-using and land-saving. Being relatively expensive and inelastically supplied land should be augmented and labor used abundantly. This leads to the conclusion that agricultural technological progress in market oriented land scarce/labor abundant countries should focus on innovation in the creation of seed varieties and fertilizers and make use of irrigation, all of which improve the quality of land ($\mathbf{q_{La}}$). In Mosk (2010) I argue that productivity improvements in Japan during the late 19th and early 20th were labor augmented **and** land augmenting. Labor was augmented through a combination of increasing hours worked per farm worker (**h**) and improving the efficiency of each hour worked [**e(h)**], largely through expansion of compulsory education throughout the country. This process of labor augmenting change took place simultaneously with land augmentation.

[7] In advancing his argument Habakkuk drew upon the work of Rothbarth (1946). For this reason the theory is often referred to as the Rothbarth-Habakkuk thesis.

[8] For a test of the labor-saving bias in American manufacturing – resting on a very specific functional form for the production function fitted to industrial sectors – see Cain and Paterson (1986).

[9] James and Skinner (1985) argue that the ratio of the wages of skilled to unskilled labor is basically the same in the United States and Great Britain.

[10] In attempting to resolve the paradox Temin (1966) concludes that American technology must have been superior to British technology. Arguing that American manufacturing made use of skilled labor, avoiding the use of unskilled labor altogether, James and Skinner (1985)

attempt to resolve the paradox on other lines. It is doubtful that American manufacturing eschewed the use of unskilled labor. For example see the discussion in Hounshell concerning practices in the Singer Sewing Machine company prior to the 1880s.

[11] Field also argues that most capital takes the form of transportation equipment and structures, not machinery. But this does detract from the point about capital being flimsy – or as I argue below more youthful than British capital – because American structures and American transport equipment were also designed along standardized lines with expected short life spans. Consider prefabricated houses – available in Chicago in the mid-19th century United States and the wagon and carriage industry that was using interchangeable parts and machine tools to turn out wheels by the second half of the 19th century. See page 148, Figure 3.11, in Hounshell (1984).

[12] See Floud (1976). Like Field, Floud is very sceptical about the validity of the Habakkuk hypothesis. He argues that up until the bicycle boom at the end of the 19th century machine the British manufacturing sector was keeping pace with the American manufacturing sector in creating machine tools that were extensively utilized in producing precision machined interchangeable parts.

[13] See Figure 4.1 on page 158 in Hounshell (1984) for a reproduction of the assembly directions. For a picture of the interchangeable parts making up a reaper sold in 1867 see page 49 in Giedion (1948).

[14] For detailed fairly technical discussions of machine tool see Rolt (1965), Wagoner (1966) and Woodbury (1972).

[15] On the role of gross nutritional intake on shaping the biological standard of living – as measured by height, weight, chest girth, and muscular capacity – see Mosk (1996).

[16] For instance in 1860 patent fees in Great Britain were on average four times the level of per capita income. In the wake of the Crystal Palace Exhibition of 1851 the patent law in Great Britain was reformed (in 1852 after years of political pressure brought by inventors and patentees), fees were reduced and application procedures were streamlined in a single "Great Seal Patent Office." See Kahn (2005: pp. 30-9).

[17] See Sokoloff and Khan (1990).

[18] See Figures 2.1 (page 35) and 2.3 (page 62) in Kahn (2005).

[19] See Kahn (2005) who devotes an entire chapter to female inventors.

[20] For an excellent photograph of Blanchard's lathe built in 1822 for use at the Springfield Armory see Figure 1.5 on page 36 of Hounshell (1984).

[21] See Angevine (2001).

[22] See figure 24 on page 48 of Giedon (1948) for an example of replaceable saw-teeth.

[23] Quotation from Crowell (1919: pp. 26-7). The British were also heavily dependent on imports of weaponry and machine tools from the United States during both World War I and World War II. See Hornby (1958).

[24] See Weber (1976).

[25] See Figure 49 in Giedon (1948). Elsewhere in Giedon (1948) there are excellent reproductions of pictures provided with patent applications for apparatuses for catching and suspending hogs (pg. 231) and automatic hog-weighing apparatuses for use in packing houses (pg. 97). Hounshell (1984: pg. 243) provides a revealing reproduction o a drawing of Norton's Automatic Canmaking Machinery from 1885, complete with a moving conveyor belt. As well he reproduces drawings of "disassembly" lines illustrating the "flow" production line in Cincinnati, eventually adopted in Chicago which became known as the "hog-butcher of the world." (Hounshell, 1984: pg. 242). By the 1890s the Westinghouse Foundary was experimenting with conveyor belts that carried machine-fabricated molds past pourers (Hounshell, 1984: pg. 240). The seeds of the Ford assembly line were laid in the three decades after the end of the Civil War.

[26] See Hounshell (1984), for instance page 85 ff and the illustrations on page 343 for the argument that the Singer Sewing Machine company did not switch over to a reliance on interchangeable parts until the 1880s. Brandon (1977) argues that the precision of milling machines was not sufficiently advanced to produce many of the components in a Singer sewing machine until mid-century. Similar comments may apply to McCormick although it is important to keep in mind that the carriage and buggy sector was making extensive use of the type of interchangeable parts later built into McCormick equipment.

[27] Scientific knowledge played an increasingly important role in the inventing of the late 19th and 20th centuries. For a discussion of machine tools in the era of electrical power see Noble

(1986). Both Giedon (1948) and Hounshell (1984) provide useful well illustrated accounts of the mechanization of the home and the push towards prefabrication in housing construction that was especially important in creating consumer demand for machines manufactured with machine tools and interchangeable parts. As well Noble (1986) emphasizes the importance of demand flowing out the aircraft sector in stimulating a massive demand for machine tools in the 20th century.

Table 1

Relative Earnings for Skilled and Unskilled Labor, United States and United Kingdom 1710-1950

Panel A: Annual Earnings of Agricultural Laborers (AL) and Engineers/Surveyors (ES) Relative to Wages for General Laborers (GL) = 100, United Kingdom, 1710-1891			
Year	**AL**	**GL**	**ES**
1710	92.5	100	682.1
1755	82.8	100	662.7
1805	109.6	100	790.4
1815	91.1	100	767.0
1819	93.6	100	782.1
1827	71.1	100	837.8
1851	64.8	100	1068.5
1871	79.8	100	1125.8
1891	66.9	100	607.2

Panel B: Annual Earnings for Civil Engineers (First, Second and Third Grade): Relative to Civil Engineers of the Second Rank; and Relative to Annual Earnings of All Male Manufacturing Workers, 1820-1859 [(a)]						
Year	**Relative to Earnings of Second Grade = 100**			**Relative to Male Manufacturing Worker Earnings = 100**		
	First	**Second**	**Third**	**First**	**Second**	**Third**
1820	230.4	100	n.e.	1107.9	481.0	n.e.
1832	247.7	100	54.7	1062.1	428.8	234.7
1850	227.7	100	51,8	971.4	426.6	221.1
1859	216.3	100	55.5	840.1	388.5	215.6

Notes: n.e. = not estimated

(a) For engineers, First grade is the most experienced; second grade has intermediate experience; and third grade is the least experienced

Sources: Carter et al (2006): Volume I (pg. 2-261); and Mitchell (1988): pg. 153.

Table 2

Population Size, Components of Population Growth, and the Human Development Index in the United States and the United Kingdom

Panel A: The United States, 1790-1913				
Period	**Immigration Rates (per 1,000 persons): Net Immigration (NIMR) and Immigration Rate (IMR) [(a)]**		**Crude Birth Rate (BR) per 1,000 Persons**	**Population (1,000 Persons)**
	NIMR	**IMR**		
1790-99	0.9	n.e	n.e.	4,512
1800-09	2.8	n.e.	54.5	6,114
1810-19	2.1	n.e.	53.2	8,229
1820-29	2.4	1.1	52.2	11,008
1831-39	5.0	3.6	50.9	14,737
1840-49	8.3	7.0	46.3	19,583
1850-59	10.3	11.7	44.1	26,649
1860-69	6.7	5.2	42.0	34,956
1870-79	5.1	6.4	40.9	44,757
1880-89	8.3	9.5	37.2	56,213
1890-99	3.7	5.4	32.7	69,189
1900-13	6.2	10.0	29.6	86,425

[Continued]

Table 2 [Continued]

Panel B: United Kingdom, Crude Birth Rate (BR) and Population Estimates (P), 1801-1913			
Population (P): Year and Census Estimate		Birth Rate (BR): Period and Estimate	
1801	10,411		
1811	11,970		
1821	14,092		
1831	16,261	1838-39	31.1
1841	18,534	1840-49	32.5
1851	20,817	1850-59	34.2
1861	23,128	1860-69	35.5
1871	26,072	1870-79	35.5
1881	29,710	1880-89	32.9
1891	33,029	1890-99	30.0
1901	37,000	1900-13	26.7
1911	40,831		

[Continued]

Table 2 [Continued}

Panel C: The Human Development Index (HDI) in the United States and the United Kingdom, 1800-1910			
United States		**United Kingdom**	
Year	**HDI**	**Year/Period**	**HDI**
1800	0.58	1801	0.38
1820	0.60	1821	0.40
1840	0.62	1841	0.43
1850	0.63	1851	0.45
1860	0.67	1861	0.50
1870	0.70	1871	0.53
1880	0.74	1881-90	0.60
1900	0.80	1901-10	0.63
1910	0.87	1920-22	0.71

Notes: n.e. = not estimated.

(a) The estimates of the net immigration rate are not necessarily consistent with the estimates of the immigration rate (the latter is based on estimates of immigrants, the former is deduced from the other components of population growth.

Sources: Carter et al (2006) [Volume 1]: pg. 1-541 and Mitchell (1978): pp. 8-9; Mosk (2005): pp. 104-8.

Table 3

Ratios of Relative Size: Population (P), National Income (Y), Income per Capita (y) and Operating Kilometers of Railroad Track (RT), the United States, the United Kingdom and France, 1840-1913

Panel A: Ratio of Value for US Divided by Value for United Kingdom (US/UK) and Ratio of Value for US Divided by Value for France (US/F), 1870-1913

Period	Population (P)		National Income (Y)		**Income per Capita (y)**	
	US/UK	US/F	US/UK	US/F	**US/UK**	**US/F**
1870-79	1.37	1.17	1.07	1.52	1.29	1.29
1880-89	1.57	1.42	1.32	1.96	1.38	1.38
1890-99	1.77	1.72	1.55	2.39	1.39	1.39
1900-13	1.99	2.12	2.08	3.33	1.57	1.57

Panel B: Ratios of Railroad Track in Kilometers (RT), 1840-99

Period	**US/UK**	**US/F**
1840-49	1.74	8.08
1850-59	2.47	5.69
1860-69	3.25	4.61
1870-79	5.01	6.12
1880-89	7.87	7.30
1890-99	10.24	10.24

Sources: Carter et al (2006) [Volume 4): pg. 4-916 and 4-923; Maddison (2006): various tables; and Mitchell (1978): pp. 315-18.

Table 4: Agriculture in the 19th Century United States, 1850-1980

Panel A: Long-Run Trends in Factor Price Ratios: Land Value/Wage Rate) – lav/w; Wage Rate/Machinery Price (w/mp); and Land Value/Fertilizer Price (lav/ferp), 1850-1980, Indices with 1910 = 100			
Year	**Lav/w**	**w/mp**	**Lav/ferp**
1850	34	38	n.e.
1860	41	54	n.e.
1870	63	30	n.e.
1880	64	54	24
1890	71	70	40
1900	64	79	47
1910	100	100	100
1920	73	154	93
1930	69	128	110
1940	58	104	79
1950	43	164	123
1960	56	183	289
1970	56	210	583
1980	99	185	812

Panel B: Vintage of Wheat Varieties in the United States, 1919			
Introduced	Percent of Acreage (%)	Introduced	Percent of Acreage (%)
Before 1800	0.2 %	1860-69	6.7 %
1800-09	0.2	1870-79	31.6
1810-19	3.6	1880-89	9.7
1820-29	0.7	1890-99	8.7
1830-39	1.7	1900-09	9.8
1840-49	1.2	1910-19	17.0
1850-59	2.0	Unknown	6.9

Table 4 [Continued]

Panel C: Percentage of Farms in the United States Reporting Tractors, Horses or Mules, Horses and Mules, 1910-1969				
Year	**Tractors**	**Horses or Mules**	**Horses**	**Mules**
1920	3.6 %	84.2 %	73.0 %	35.0 %
1930	13.5	79.9	n.e.	n.e.
1940	23.9	71.5	51.6	30.3
1950	46.9	54.0	39.4	20.5
1969	80.8	20.0	n.e.	n.e.

Panel D: Range in Precipitation (per), Annual Temperature (tem), Latitude (lat) and Longitude (lon) for Corn, Cotton, Tobacco and Wheat Planted in the United States, 1840 and 1910 [(a)]								
Variable	**Corn**		**Cotton**		**Tobacco**		**Wheat**	
	1840	**1910**	**1840**	**1910**	**1840**	**1910**	**1840**	**1910**
Per	16.5	20.9	11.7	20.7	11.1	11.8	13.8	24.3
Tem	12.4	14.4	5.9	6.1	4.2	9.7	10.9	16.6
lat	7.3	8.0	4.1	4.1	2.6	4.1	6.8	9.9
Lon	13.4	14.8	10.4	16.6	11.3	11.3	11.0	29.8

Panel E: Indices for the Acreage in Farm Land, Grazing Land and the Farm Population of the United States, 1850-1969 (1900 = 100)			
Year	**Farm Land**	**Grazing Land**	**Farm Population**
1850	35.0	n.e.	n.e.
1870	48.6	n.e.	n.e.
1900	100.0	100.0	100.0
1940	126.4	92.4	102.3
1969	126.8	79.3	34.5

Table 4 [Continued]

Panel F: The Expanding Role of the West in the Agriculture of the United States, 1850-60: Indices for Western Farm Land (wfla), Western Farm Population (wfp), Irrigated Land (ila); Percentage of the US Farm Land in Western Farms (wfla%) and Percentage of Irrigated Land in the West (wila%), 1850-1969					
Year	**Indices (1900 = 100)**			**Percentages (%)**	
	Wfla	**Wfp**	**ila**	**wfla%**	**wila%**
1850	4.8	n.e.	n.e.	1.6 %	n.e.
1870	16.8	n.e.	n.e.	4.0	n.e.
1900	100.0	100.0	100.0	11.5	96.8 %
1940	269.5	200.2	228.6	24.4	95.9
1969	343.8	84.5	461.2	31.2	88.9

Notes: n.e. = not estimated.

(a) The ranges refer to the differences in the percentages of land that are the coldest versus the warmest regions of the country in the case of temperature, in the driest versus the wettest regions, in the furthest north versus the furthest south, and in the furthest west versus the furthest east.

(b) For the irrigation figures, seventeen states are included in the list of Western states. For the remainder of Panel F, the West is defined as the sum of the following states: Montana, Idaho, Wyoming, Colorado, New Mexico, Arizona, Utah, Nevada, Washington, Oregon, California, Alaska and Hawaii.

Sources: Mosk (2005); pp. 55-6; and Olmstead and Rhode (2008): pp. 9, 32, 376 and 394.

Table 5

Patents in England and the United States Classified by Number of Patents Awarded to Patentee, 1790-1850

Distribution of Patents Classified by the Number of Patents Awarded to a Patentee Over His/her Career (%)						
Country	**1 Patent**	**2 Patents**	**3 Patents**	**4-5 Patents**	**6-9 Patents**	**Over 10 Patents**
			1790-1811			
England	52.2 %	23.6 %	9.8 %	8.3 %	4.7 %	1.4 %
US	51.0	19.0	12.0	7.6	7.0	3.5
			1812-1829			
England	42.9	18.9	13.1	10.9	8.0	6.3
US	57.5	17.4	7.1	7.6	5.5	4.9
			1830-1842			
England	46.1	20.6	10.0	11.1	3.9	8.3
US	57.4	16.5	8.1	8.0	5.6	4.4
			1843-1850			
England	51.8	14.5	10.9	10.9	5.2	6.7
US	60.5	17.7	8.8	7.2	2.4	3.5

Source: Kahn (2005): pg. 112.

Table 6

Literacy and Peasant Farming in France, 1863-1963

Panel A: Literacy in France in 1863. Averages for Public School Children Aged 7-13 Years of Age: Percentage of Schoolchildren Unable to Read or Speak French (uswf%); Percentage Able to Speak but Unable to Write French (suwf%), and Percentage Able to Speak and Read French (swf%) Averages for Groups of Departments Classified by Number of Communes in Which French is Not Spoken (fnsc)		
uswf%	**suwf%**	**swf%**
fnsc = 0 (55 departments)		
3.6 %	39.2 %	57.2 %
fnsc above 0, less than 50% (10 departments)		
14.9	26.9	58.2
fsnc above 50%, less than 90% (8 departments)		
27.6	38.9	33.5
fsnc 90% or above (16 departments)		
34.4	29.2	36.3
All of France		
14.0	34.1	51.9

[Continued]

Table 6 [Continued]

Panel B: Distribution of Farms (farms%), Area of Farmland Used in Agriculture (ala%), and Number of Persons Working Fulltime in Farming (flab%) on Various Types of Farms; and Average Land Area per Farm (in Hectares), avla, 1963				
Type of Farm	**Avla**	**farms%**	**ala%**	**flab%**
Small Peasant – Part Time	1-10 hectares	45 %	12 %	29 %
Medium Peasant	10-20 hectares	27	22	29
Large Peasant	20-50 hectares	22	37	30
Family Capitalist	50-100 hectares	4.7	17	8
Capitalist	100 hectare +	1.3	12	4

Sources: Franklin (1969): pg. 74 and Weber (1976): pp. 498-501.

Table 7

Number of Singer Sewing Machines and McCormick Machines (Total of Hand Reapers, Self Rakers, Mowers, Droppers, Harvesters, and Binders) Produced, 1841-1885

Period	Singer Sewing Machines [a]	McCormick Machines
1841-55	n.a.	27
1846-50	n.a.	887
1851-55	857	1,442
1856-60	6,748	4,381
1861-65	26,043	4,969
1866-70	69,651	8,658
1871-75	233,920	8,922
1876-80	382,283	15,738
1881-85	n.a.	45,848

Notes: n.a. = not available

(a) The average figure for 1851-55 is actually for 1853-55.

Source: Hounshell (1984): pp. 89 and 161.

Table 8

Major Inventions in Four Industries (Railroads, Agriculture [Mechanical], Petroleum and Paper) Between 1797 and 1957 in Five Countries (the United States, the United Kingdom, France, Germany and Russia) and % of Inventions Made in the United States (US %) [(a)]

Panel A: Important Inventions in Railroads [(b)]								
Period	US	UK	France	Germany	Russia	Other [(c)]	Unknown	US %
1800-50	36	28	3	1	0	1	2	50.7%
1851-1900	53	34	5	3	0	4	6	55.8
1901-57	29	1	0	2	0	4	20	51.8
Panel B: Important Mechanical Inventions in Agriculture [(d)]								
1797-1850	43	22	0	1	0	0	4	61.4
1851-1900	82	4	0	0	0	5	19	74.6
1901-54	26	3	2	0	0	4	6	63.4
Panel C: Important Inventions in Petroleum [(e)]								
1813-50	2	2	4	0	1	0	1	20
1851-1900	25	9	4	1	5	3	8	45.5
1901-56	179	20	2	4	11	5	15	75.9
Panel D: Important Inventions in Paper [(f)]								
1788-1850	27	41	5	2	0	1	3	34.2
1851-1900	36	16	1	4	0	6	1	56.3
1901-45	14	2	1	1	0	0	1	74.7

[Continued]

Table 8 [Continued]

Notes: (a) In cases where I could not identify the national origin of the invention in the lists given in Schmookler (1966) I classified it as unknown.

(b) During the first period inventions include the high pressure steam engine; the four cylinder engine; the T-shaped iron rail; the super heater; the vacuum brake; the compound locomotive; during the second period, inventions include improved passenger cars; car ventilators; the self-feeding tender; the US signal system; the refrigerator car; automatic air brakes; the two cylinder compound engine; electric lights for locomotives; and the traction system for mountain railroads. In the third period inventions include the butt-welded firebox; the diesel-electric locomotive; triple articulated 2-8-8-8-2 locomotives; the turbo-locomotive, and centralized traffic control systems.

(c) Other nations include: Belgium, Switzerland, Spain, Sweden, Austria and Italy in the case of railroad inventions; Sweden, Denmark, Switzerland, Canada and Argentina in the case of agriculture; Canada, Hungary, Romania, Italy, and the Netherlands in the case of petroleum; and Canada, Sweden, Austria and Poland in the case of paper.

(d) During the first period inventions include the cast iron plow; the winnowing machine; steam driven plough; the threshing machine; the reaper with sickle; the horse driven reaper; the horse drawn corn planter; the grain drill; the corn harvester; and the grain binder using twine. In the second period inventions include the grass mower; the hand operated cotton picker; the self-propelling agricultural steam engine; the steel windmill; the gang plow; the wagon-type fertilizer spreader; the steam tractor hay loader; the milking machine; and the cream separator. In the third period inventions include the self-propelled cotton picker, the continuous milk machine; the automatic twine binder, and the diesel tractor.

(e) In the first period inventions include the steam super heater; the use of oil as a lamp illuminant; refining process for oil using sulphuric acid and caustic soda. In the second period thermal cracking; distillation processes; pyrometer; continuous distillation processes; continuous drilling process; continuous cracking process; use of unsaturated gasses in production. In the third period inventions include the hydrogeneration of lamp oil; the cracking of kerosene; the high-vacuum distillation process; thermal cracking process; cracking process with reactors; ultra high vacuum distillation process; and low-pressure vapor-phase cracking process.

(f) In the first period, inventions include the first continuous paper making machine; process producing pulp from corn husks; Fourdrinier machine improvements; pulp dresses; steam cylinders in Fourdrinier machines; and groundwood pulp paper. In the second period inventions include sulphite processes; the diaphragm screen; the alkaline sulphic cooking process; and the continuous process for producing parchment paper. In the third period inventions include multistage bleaching processes and the sulphite pulping process.

Source: Schmookler (1966): pp. 269-328.

Figure 1

Technological Change in Two Different Factor Environments

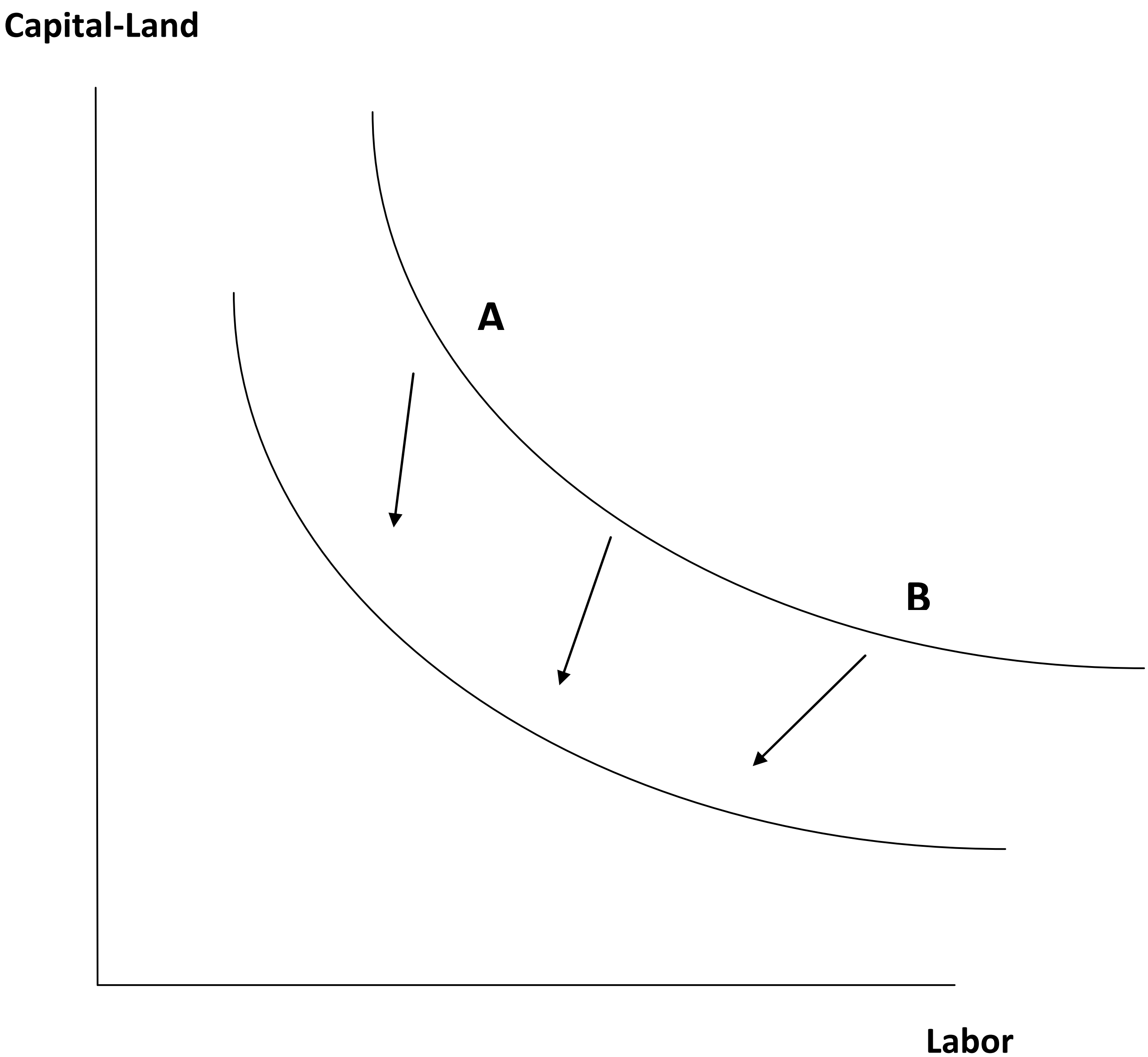
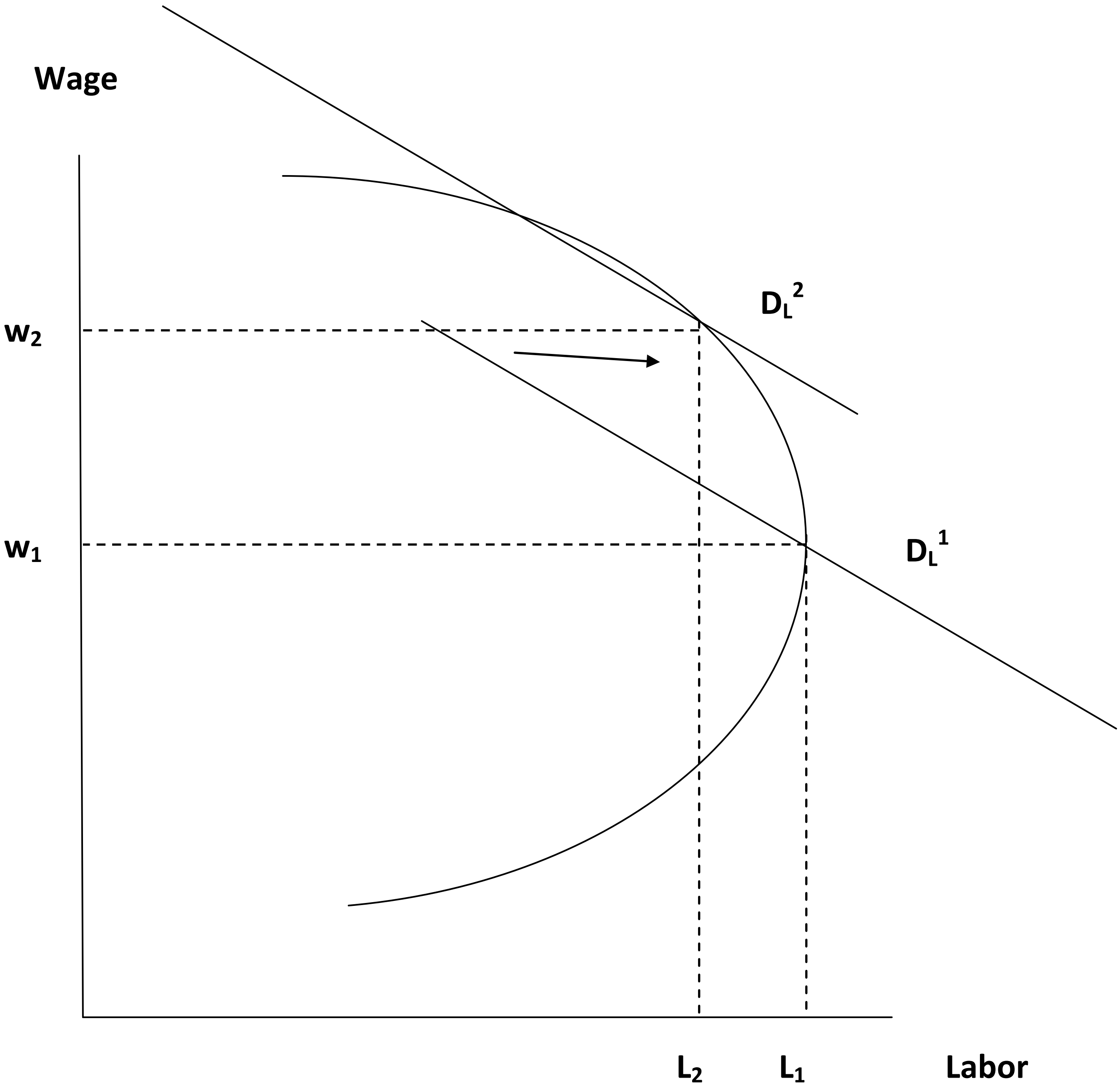


Figure 2

Backward Bending Supply Curve for Labor



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