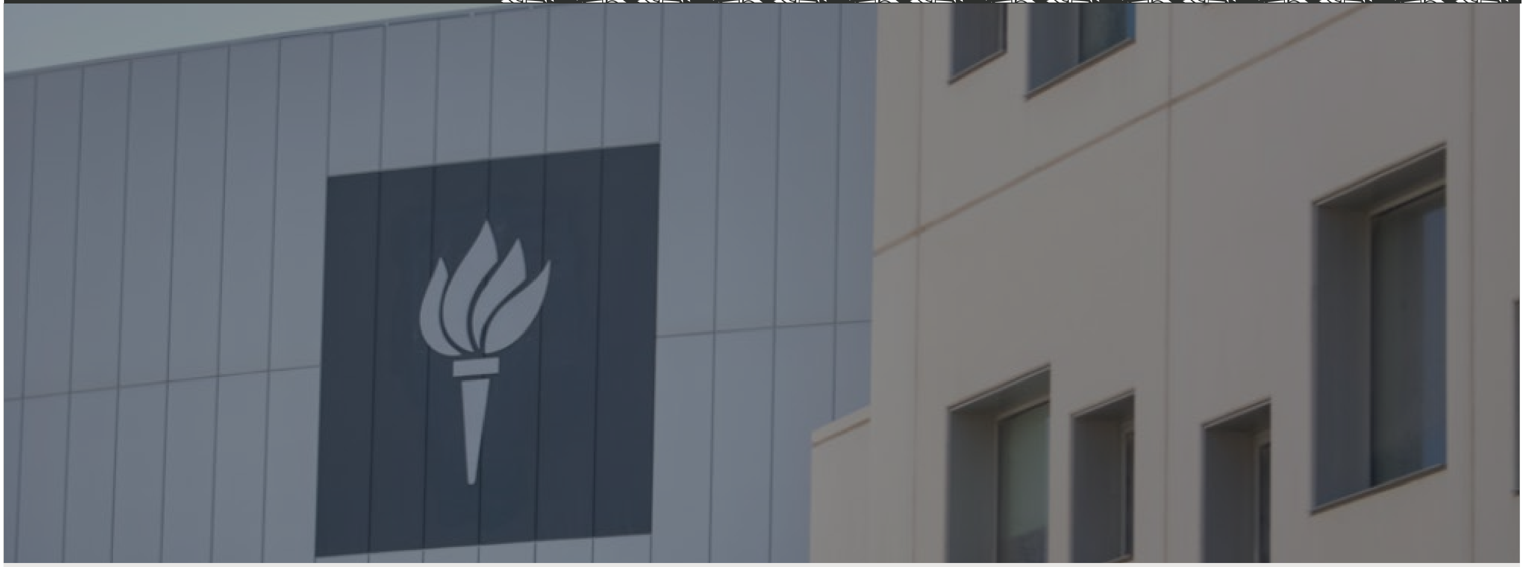
جامعة نيويورك أبوظبي
NYU | ABU DHABI



The Hand-Loom Weaver and the Power Loom: A Schumpeterian Perspective

Robert C. Allen

Working Paper # 0004
May 2017

Division of Social Science Working Paper Series
New York University Abu Dhabi, Saadiyat Island P.O Box 129188, Abu Dhabi, UAE
https://nyuad.nyu.edu/en/academics/divisions/social-science.html

The Hand-Loom Weaver and the Power Loom: A Schumpeterian Perspective **REVISED**

by

Robert C. Allen

Global Distinguished Professor of Economic History
Faculty of Social Science
New York University Abu Dhabi
P.O. Box 129188
Abu Dhabi
United Arab Emirates

Senior Research Fellow
Oxford University

Nuffield College
New Road
Oxford OX1 1NH
United Kingdom

bob.allen@nyu.edu

The empirics of this paper rest on John Lyon's Ph.D. dissertation *The Lancashire Cotton Industry and the Introduction of this Powerloom, 1815-1850*. This is an impressively well informed and thorough reconstruction of the technology and economics of the industry. This paper could not have been written without it. John Lyons sadly died in 2011. I dedicate the paper to him.

This is a revised version of a discussion paper originally issued as
Oxford University, Working Papers in Economic and Social History, Number 142, 2016

2017

Abstract

Robert C. Allen

The Hand Loom Weaver and the Power Loom: A Schumpeterian Perspective

,

Schumpeter's 'perennial gale of creative destruction' blew strongly through Britain during the Industrial Revolution, as the factory mode of production displaced the cottage mode in many industries. A famous example is the shift from hand loom weaving to the use of power looms in mills. As the use of power looms expanded, the price of cloth fell, and the 'golden age of the hand loom weaver' gave way to poverty and unemployment. This paper argues that the fates of the hand and machine processes were even more closely interwoven. With the expansion of factory spinning in the 1780s, the demand for hand loom weavers soared in order to process the newly available cheap yarn. The rise in demand raised the earnings of hand loom weavers, thereby, creating the 'golden age'. The high earnings also increased the profitability of developing the power loom by raising the value of the labour that it saved. This meant that less efficient–hence, cheaper to develop--power looms could be brought into commercial use than would have been the case had the golden age not occurred. The counterfactual possibilities are explored with a model of the costs of weaving by hand and by power. The cottage mode of production was an efficient system of producing cloth, but it self-destructed as its expansion after 1780 raised the demand for sector-specific skills, thus providing the incentive for inventors to develop a power technology to replace it. The power loom, in turn, devalued the old skills, so poverty accompanied progress.

JEL codes: N63, N34, O31

keywords: technological change, invention, technological unemployment, creative destruction

Schumpter (1994, pp. 84, 87, 88) maintained that capitalism progressed through 'a perennial gale of creative destruction' in which new modes of production with higher productivity replaced older modes with lower productivity. In the course of advance, outmoded machinery was junked, and workers with old fashioned skills lost their livelihoods as they too landed on the scrap heap of history. The genius of capitalism resides as much in the destruction of the old as in the creation of the new.

At the industry level, we can see the individual gusts that made up Schumpeter's gale. The Industrial Revolution consisted of one blast after another. In textile production, where one stage (spinning) fed into another (weaving), a technological breakthrough in one created an inbalance that led to a technological breakthrough in the next. The result was waves of creative destruction.

The first bottleneck occurred in spinning. The spinning of wool, flax, and later cotton was carried out by women working in cottages across England. Earnings were similar across all the sectors since women shifted between them, and all were eventually mechanized. As the wool industry expanded in the seventeenth century due to an abundance of long haired sheep and growing demand from Britain's expanding mercantile empire, the employment of women rose. By the end of the seventeenth century, the labour market was tight, and their wage jumped up. The rise in their wage meant that Hargreaves' spinning jenny and Arkwright's water frame, which would not have been profitable to use in the conditions of the seventeenth century, suddenly became profitable. As a result, Hargreaves and Arkwright expended the resources to develop them. By the 1770s, commercially viable designs were developed, and the factory production of textiles took off. The cottage mode of production was destroyed as women stopped spinning in their cottages, and their wheels were tossed in the barn. The 'contradiction' that led to the destruction of the cottage mode of production at its zenith was the shortage of skilled spinners (rather than the immiseration of the workforce that Marx (1867, Part 8, chapter 30) supposed). Their high wages led inventors to develop a replacement technology that overturned the cottage mode and created the factory mode (Allen 2015, 2017).

This paper is about the next gust of creative destruction–the invention of power weaving and the demise of the hand loom weaver. The course of events was similar. The invention of machine spinning led to a huge supply of cheap yarn. This led to inbalance between the sectors. The demand for weavers shot up from about 37 thousand in 1780 to 95,000 in 1792 to a peak of 240,000 in 1820 (Table 1). As employment expanded in the late eighteenth century, the earnings of weavers were also bid up producing a Golden Age during the Napoleon Wars (Bythell 1969). It was the high wages earned by hand loom weavers in that period that led to the development of the power loom, for the high wages meant that less advanced versions of the power loom could be used commercially than would have been the case had wages remained at their earlier, lower levels. Less R&D expenditure was necessary to make the transition from experimental designs to operational prototypes than would have been necessary earlier or would have been the case in other economies where wages were lower. This was the 'contradiction' through which the expansion of the cottage mode of production led to its own demise, as the factory replaced it. Once again the cottage mode of production was destroyed at its zenith not by the immiseration of the work force but by its prosperity. Immiseration quickly followed, however, for wages collapsed in the 1820s and employment levels followed in the 1830s and 1840s. Between about 1815 and 1845, the share of cotton cloth woven by power increased from 5% to 95% (Table 1). The weavers lost the high rent jobs they had enjoyed, and hand looms eventually became play things for the artsy-craftsy middle class.

These stories of technical change in the cotton industry bear on general explanations of the Industrial Revolution since they emphasize the importance of demand factors driving economic progress. Many widely accepted views emphasize factors affecting the supply of technology. Clark (2007) has offered a cultural explanation for the Industrial Revolution (in the aftermath of the black death, a ‘genetic process’ produced a British population that was better behaved and more responsive to economic incentives than people elsewhere), as has Mokyr (2002) (in the aftermath of the scientific revolution, communications networks sprang up in Britain in which natural philosophers offered businessmen tips on how to respond more scientifically to economic opportunities).[1] On the other hand, North and Weingast (1989) and Acemoglu and Robinson (2012) have offered a political explanation (the Glorious Revolution replaced arbitrary royal government with the rule of law and security of property with the result that businessmen responded to economic incentives rather than being distracted by rent seeking). What these theories have in common is a focus on the responsiveness of economic actors to incentives in the market. The cultural or political change led businessmen and inventors to become more rational, savvy, confident, or focussed and consequently to respond better to their opportunities. The limitation of all of these theories is that they leave those opportunities unexamined.[2] Did inventors in late eighteenth century England face the same opportunities as their ancestors or their counterparts in other countries? Was the Industrial Revolution the result of an unusual responsiveness to incentives or was it the result of unusual incentives? The Schumpeterian perspective explored here emphasizes how the evolution of markets created the incentives that inventors faced and can explain the timing of their efforts more precisely than other approaches.[3]

The theory of induced innovation

My analysis of the power loom is an application of the theory of induced innovation. This theory of technological change was originated by Sir John Hicks’ *Theory of Wages* (1932, p. 124) when he suggested that "a change in the relative prices of the factors of production is itself a spur to invention, and to invention of a particular kind—directed to economizing the use of a factor which has become relatively expensive." Hick’s claim was little more than a conjecture, and economists have been elaborating it since. Theoretical papers in the 1960s (Kennedy 1964, Samuelson 1965) produced models capturing some

---

[1] O’Brien (1997) examined the life and writings of Edmund Cartwright, the inventor of the power loom, in detail to investigate Mokyr’s view and found no evidence in support of it.

[2] Studies of specific technologies of the industrial revolution have paid more attention to the incentives created by the profitability of old and new techniques than the more general treatments mentioned here. See, for instance, Hyde (1977), von Tunzelmann (1978), Nuvolari and Verspagen (2009), and Allen (2009). These studies were following a tradition that assessed Victorian entrepreneurship in profitability terms (McCloskey 1973, Sandberg 1974).

[3] Despite my Schumpeterian approach, this paper is influenced by Harley (1971, 1973).

features of Hick's insight but with peculiar assumptions about firm behaviour like the maximization productivity growth rather than profit (Acemoglu 2003). Empirical research, primarily concerning agriculture and energy, however, found support for the induced innovation framework (Hayam and Ruttan 1971, Newell, Jaffe, and Stavins 1999, Popp 2002, Aghion et al 2016).

The development of endogenous growth theory provided a richer environment to model induced innovation in a more plausible way. An important first step was Acemoglu's (2002b) research on 'directed technical change." The model was developed to explain why the stock of educated workers and their earnings were both rising in the United States in the late twentieth century. Acemoglu posited a production function in which output depended on both educated and uneducated labour. The productivity of each could be augmented by new machines, which, in turn, were supplied by monopolistic suppliers. They allocated resources between the two types of labour in response to profit opportunities, which depended on relative wages–a nod to Hick's 1932 proposal–and potential market size. A greater supply of a factor, educated labour for instance, could cause an increase in the demand for that factor that exceeded the increase in supply. When that happened, the wage of educated labour could rise even as its supply was rising. This unexpected result diluted the support the model gave to Hick's view.

The 'directed technical change' model has been applied to economic history. Acemoglu (2002a, p. 12, 42-3) believed it captured the essence of Habakkuk's (1962) work on labour scarcity and American technology in the nineteenth century as well as the invention of the cotton mill in Britain during the Industrial Revolution. Hanlon (2015) is a compelling application of the model to invention during the cotton famine of the early 1860s.

In 2010, Acemoglu re-engaged with the issue of labour scarcity and developed conditions under which it would–or would not–influence the direction of technical change in a theoretical model. This was an important step in moving beyond factor augmenting representations of technical change, which preclude this possibility.

Acemoglu and Restrepo (2017) propose a new and more compelling model of induced innovation that builds on Acemoglu (2010) and gives clearer expression to Hick's intuition. This model is prompted by concerns about the impact of automation on wages and the distribution of income with obvious parallels to the handloom weaver and the power loom. In the new model, GDP is determined by the productivity of labour in tasks. Tasks can be accomplished by labour alone or in conjunction with machines. Technical change involves either the mechanization of existing tasks (robots building automobiles) or the creation of new complex tasks that are performed by people alone (personal assistants). Monopolistic suppliers of technology can create either new machines or new complex tasks, and the choice depends on the relative profitability of the two options. "The task-based framework–differently from the standard models of directed technological change which are based on factor-augmenting technologies–implies that as a factor becomes cheaper, this not only influences the range of tasks allocated to it, but also generates incentives for the introduction of technologies that allow firms to utilize this factor more intensively." (Acemoglu and Restrepo 2917, p. 36) Conversely, when a factor–e.g. labour–becomes more expensive, technology is developed to economize on its use as Hicks suggested.

In the Acemoglu-Restrepo model, the immediate impact of automation is always detrimental to workers. "Automation always reduces the labor share and employment, and may even reduce wages." (p. 3) This is an alternative explanation to the wage stagnation in Britain in the first half of the nineteenth century (Allen 2009). However, an important feature of the Acemoglu-Restrepo model is that a capitalist economy includes 'selfcorrection' features to prevent automation from rendering everyone unemployed: As automation proceeds, wages fall, and this increases the incentive for firms to shift resources towards inventing more complex tasks. Under many circumstances, the expansion of employment in those sectors stabilizes employment and earnings. Presumably the expansion of new high productivity jobs later in the nineteenth century was the immediate cause of the rise in real wages that began around the 1840s (Allen 2009, 2017).

A full scale application of the Acemoglu-Restrepo model to the industrial revolution would include an analysis of the creation of new, complex tasks manifest in the vast expansion of middle class jobs during the period (Allen 2017, pp 60-71). The focus of this paper, however, is narrower and concentrates on one of the dramatic episodes of mechanization–the invention and diffusion of the power loom. In Acemoglu-Restrepo terms, the 'task' that was transformed was weaving cotton yarn into cloth. Workers could do it by hand with virtually no capital or with power looms, which were very capital intensive for the period. The invention of the spinning mill, which flooded the market with cheap yarn in the 1780s, was a shock which raised the weaver's wage above its balanced growth path. Inventors responded by directing resources to perfecting the power loom. Its introduction into commercial use caused a sharp decline in the employment and wages of handloom weavers, as predicted by the model.

the handloom sector

The first step in developing this view of the economy is describing the technologies of the period. The handloom was the traditional device for weaving cloth. While it was thousands of years old, the system of business organization was comparatively modern. Looms were ordinarily located in the cottages where the weavers lived, and, for that reason, I refer to this system of business organization as the cottage mode of production. The weavers were employed as contract employees by manufacturers, who supplied them with yarn, collected the finished cloth, and paid the weavers by the piece.

To understand the invention of the power-loom and the competition between it and the handloom, it is necessary to know the evolution of weavers' incomes. There are many contemporary estimates of weekly earnings. In reality, there was a range of income reflecting differences in skill and effort. To deal with that situation, Wood (1910, pp. 425-33, 593-6), Bowley 1902, pp. 106-8, 112-4) and Palgrave (1926, pp. 634-5), who collected this information, usually recorded the income of either a 'good' or an 'ordinary' worker. Feinstein (1998, p. 189) combined some early figures with Wood's index for the latter part of the period to form the series in Figure 1. In 1770, earnings were not particularly high, but they grew rapidly in the next twenty years as the factory production of cotton yarn exploded and along with it the demand for weavers. The years from 1793 to 1817 were the "halcyon days" in which "the hand-loom weaver was in the enviable position of a man who had something valuable to sell and could make very comfortable terms for himself." (Hammond and Hammond 1919, p. 18) After Waterloo, the hand loom weaver's fortunes reversed, and their circumstances became grim, indeed.

As well as organizing production, the manufacturer inventoried raw materials and finished cloth. He also prepared the beam, that is the shaft around which was wound the thousands of lengths of yarn that comprised the warp of the cloth. These beams were then mounted on the looms and were crisscrossed with weft as each piece of cloth was woven. The profit earned by the manufacturer for a piece of cloth equalled the price of the piece minus the cost of the yarn, the payments to the weaver, and the other costs of doing business.

Hence, a second way to calculate the weaver's income is to subtract yarn and manufacturers' costs from the sale price of the cloth.

income/wk = (price - yarn cost - manufacturers' costs and income) * pieces per week (1)

This method corroborates the contemporary estimates, as will be shown for two specific types of cloth.

There was a great variety of cloths, that differed in terms of the fineness of the yarn and the character of the weave. I concentrate on what has come to be called Neild printer's cloth[4] since it was an industry standard that was widely produced and has been well documented. The precise specification of the cloth is important to work out its cost and the earnings of weavers. A piece of Neild cloth was 29 yards long and 28 inches wide. It was woven with 36 count yarn with a weave of 84 threads per inch of weft and 77 threads per inch of warp. Each piece contained 2.215 pounds of warp and 2.415 pounds of weft (Lyons 1977, p. 195).

How much of this cloth could be woven in a week? The answer depended on how many hours the weaver worked and how much was produced each hour. There was a considerable range in productivity, so I concentrate on a 'good' male working full time. Following Voth's (2000, pp. 118-33) analysis of the working day, I assume that weavers worked five days per week (they rested on Sunday and celebrated Saint Monday) and 11 hours per day. One and a half of those work hours were, however, devoted to eating, so actual work hours were 9.5 per day or 47.5 per week. A work day of 9 hours is taken as the standard in the Indian *Report of the Fact-Finding Committee (Handloom and Mills)* (1942, pp. 57-9), which provides some corroboration. In addition, these studies show that only about 65% of the weaver's work time was actually spent moving the shuttle across the loom ('uptime'). The other 35% was taken up with set-up tasks and repairing broken threads ('downtime')[5].

How much cloth was produced depended on how many times per minute the shuttle moved across the loom when weaving was actually under way. Each traverse of the shuttle constituted a pick, and the pick rate of a good weaver was said to be 100 shots per minute during the Industrial Revolution.[6] Confirmation of this figure comes from Egyptian and modern Indian sources that report similar values. (Latif 1997, p. 197, Clark 1908, p. 51). Allowing for 35% 'downtime,' the good weaver achieved a speed of 65 picks per minute averaged over the working day. (In this paper the speed of a loom will mean the average speed over the day, which equals the speed while in operation multiplied by the fraction of the day the loom operates, its 'uptime'.) Given that printer's cloth contained 84 threads per inch of weft, a weaver produced 61.26 yards per day. In a year a weaver produced 3062.5 yards or 105.6 pieces of 29 yards each.

While printer's cloth is the focus of this study, I also analyse a coarser cloth that was

---

[4] A price series for this specification of cloth was originally published by Neild (1861).

[5] Latif (1997, p. 197).

[6] This rate is achieved on cloth one yard wide. On broadcloth, the rate dropped to 80. White (1846, pp. 32-3).

more typical of production in the early stages of the cotton industry to estimate weaver's earnings. The paradigm is Cardwell's 'fine' calico, whose price was reported by Harley (1998, p. 79) for the period 1779-98. It was made from 20 count warp and 18 count weft[7]. We do not have a description of the cloth reporting the number of warp and weft threads per inch, but these can be worked out from the norms for Indian hand woven cloth in the 1950s.[8] Again assuming that the weaver makes 100 picks per minute during his 'up time,' he wove 3.66 pieces per week of 28 yards each, and each piece required 3.598 lbs of warp and 3.68 lbs of weft.

With these analyses of the productivity of a handloom weaver, we can calculate the income per day of the weaver from the prices of cloth, yarn, and manufacturers' costs. Figure 2 shows the implied incomes of 'good' male weavers from 1770 through 1839[9]. The figure also shows the daily income of a building labourer. In 1768 when Arthur Young visited Manchester, a weaver earned about 70% of a building labourer's wage. Around 1780, at the start of the great cotton boom, hand loom weavers had high earnings making coarse cloth, but by the late 1780s and for the early 1790s, their earnings (while variable) were like those of labourers.

From the late 1790s, the earnings of handloom weavers surged, and they earned much more than labourers for the next 20 years (although their earnings dropped briefly after the resumption of war in 1803). The premium was the 'rent' that the handloom weaver earned as

---

[7] Harley (1998, P. 79) states that the cloth was made with 18 count yarn. Harley reports a price for 18 count weft but 20 count warp, and so I base costs on that description.

[8] Amalsad (1961) not only explains the methodology but provides a worked example on pp. 20-22 that can be readily adapted to Cardwell's fine calico. Amalsad's example is for a piece of Grey Long Cloth 36 inches wide and 40 yards long with a warp of 20 count and a weft of 18 and a 54 x50 weave.

[9] The data to calculate income are taken from the following sources:
price–price of a piece of printer's cloth for 1812-60 as reported by Neild (1861), standardized for size by Lyons (1977, p. 195), and extended back to 1781 by Harley (1998, pp. 80-2). For Carldwell's fine calico, I use Harley (1998, p. 79).
yarn prices–for Neild cloth, see Appendix. For Caldwell's fine calico, 18 count weft was taken from Harley (1998, p. 74) and 20 count warp from Harley (1998, p. 75) with some interpolations based on the price of 18 count weft.
manufacturer's current costs–from Lyons (1977, pp. 244-7).
manufacturer's fixed capital costs–Lyons (1977, pp. 250-1)
manufacturer's working capital costs–Lyons (1977, pp. 251-2). The value of inventory was a function of its price, and it was necessary to solve this out in computing the supply price of handloom cloth when the weaver's wage was changed to the building labourer's wage.
manufacturer's income–set to £130 per year in 1815 on a production rate of 22500 pieces per year (Lyons 1977, p. 211n20). This output equalled the capacity of the warping machine and corresponded roughly to that of Lyon's model power mill at the same date. Entrepreneurial income was kept constant in later years in view of the roughly constant nominal wage level in manufacturing. Incomes before 1810 were reduced in accord with the wage of a building labourer in Lancashire.

a return to his now scarce skill. On average from 1793 to 1817, rent increased the handloom weaver's earnings by 93% compared to what their earnings would have been had the pattern of the 1770s continued to prevail.[10] This period was the famous 'golden age of the handloom weaver.' It was important in the social history of the period, and it was important for its technological history, as we shall see.

The invention of the power loom

The Rev. Edmund Cartwright[11] is credited with inventing the power loom, although he never succeeded in making a commercially viable model. In 1784 while in Matlock on holiday, he dined with 'some gentlemen from Manchester' and proposed that weaving be mechanized as spinning had been. Cartwright's suggestion was inspired by French automatons–the mechanized figures that moved in lifelike ways.[12] If a mechanical woman could play a dulcimer, couldn't she also weave calico? Despite knowing little of machinery, Cartwright made a mechanical loom after his holiday. The device was cumbersome and required two men to operate; nonetheless, he received a patent for it.

Cartwright's loom was not commercially viable and illustrates the fundamental character of eighteenth century invention. Invention was not primarily about novel ideas; instead, it consisted of the practical engineering that converted often banal ideas into reliable machines that were cost effective in production. As Thomas Edison quipped, 'invention is one per cent inspiration and ninety-nine percent perspiration." Since invention meant R&D, it required the expenditure of money and resources, and so it responded to economic incentives.

Cartwright expended a fortune trying to perfect his loom. He employed skilled mechanics to do the work and received patents on improved designs in 1786, 1787, and 1790. In the late 1780s, he built a 20 loom mill, powered first by a bull and then by a steam engine. In 1790, a 400 loom mill was built by leasees, but it was burnt down. That was the end of Cartwright's experiments. He had invested about £30,000 in the power loom.

Other inventors also worked on the problem in the 1790s. (Cartwright complained about infringements of his patents and was awarded £10,000 in compensation by Parliament in 1809.) The key breakthrough was made by William Horrocks in Stockport. He started working with power looms in 1795 and had about 50 in operation in 1800. In 1802 he received a patent for his major invention which was the use of a crank to drive the parts of the loom rather than cams as in the earlier designs of Miller and Austin. Horrocks' loom was the first to make the transition from R&D to commercial use (Timmins 1996, p. 46, Lyons 1977, p. 69, 115, 116 n. 6).

Productivity growth in power weaving

---

[10] In 1793-1817, the earnings of the handloom weaver were 93% greater than their counterfactual earnings equal to 70% of a building labourer's wage.

[11] This section is based on Cartwright's biography by Hunt (2004).

[12] He adduced as an example the mechanical chess player then on display in London (Marsden 1895, p. 60). This has since been shown to have been a fraud. See the entry for the Turk in Wikipedia.

Power weaving was much more capital-intensive than hand weaving. It required a multi-storey building, a steam plant for power, and many looms since operations had to be on a large scale.[13] The factory also housed dressing, winding, warping, and looming machines. In the first half of the nineteenth century, there were improvements in the design of the steam plant and in some ancillary machinery, but productivity growth in power weaving was primarily driven by two major improvements. One was the invention of the dressing machine by Thomas Johnson of Stockport and patented by him and his employer William Radcliffe in 1803 and 1804 (Radcliffe 1828, Baines 1835, pp. 231-4, Marsden 1895, p. 70). This allowed the warp to be sized with flour before being mounted on the loom and thereby saved the weaver a protracted period of winding and dressing rather than weaving. The upshot was that a weaver (plus an assistant) could operate two looms instead of only one, and that pushed up labour productivity.

The other major improvement was a series of advances that increased the speed of the power loom. This also raised output per worker since each loom produced more fabric in a given time period. Horrocks' 1802 design had an average speed of 35 picks per minute (probably with an operating pick rate of 52 and an 'uptime' of 65%). This was obviously less than the average speed of a good handloom weaver (65 picks per minute). How could it compete? It had three advantages. The first was that Horrocks' loom was installed in a factory where it could be worked for 12-14 hours per day rather than the shorter day worked by a handloom weaver in his cottage. This is an example of Marglin's (1974) thesis that factories gained their advantage over hand workers by allowing the owner of the factory to dictate the pace and duration of the work day. The second was that the power loom was operated by women who were paid less than handloom weavers earned–another aspect of Marglin's theory. The third factor making the power loom commercially viable was the invention of the dressing machine, which increased labour productivity on power looms.

Horrocks' loom was the first commercially successful design, but it was slow and only marginally competitive.[14] A famous series of improvements were made in loom design in the next half century, and they increased the speed and extended the loom's capacities to finer and finer weaves. In the first two decades of the nineteenth century, a small number of firms installed power looms and the speed achievable with Horrocks' design was boosted to about 65 picks per minute. The capacity of the power loom was extended from coarse calicos to medium grade fabrics like printer's cloth. (Lyons 1977, pp. 116-7, 181) The next major advance was due to a set of improvements patented by Richard Roberts in 1822. They increased the average speed to about 76. In 1828 William Dickson invented the over pick loom, which became the normal British design. By 1836 looms had achieved speeds of about 100 picks per minute. In 1842 the uptime and the speed were both increased by improvements designed by William Kenworthy and James Bullogh. Their loom had an

---

[13] In Coventry in the 1850s, power looms were used to weave silk ribbons, and numerous 'cottage factories' were built in which looms were located in weaver's cottages but supplied with power from a central engine. This arrangement was more costly than factory operation. See Searby (1972, pp. 194-223, 497-554) and Marx (1867, p. 304).

[14] Horrock's firm was in continuous operation until 1814, suggesting he covered his costs, but the power loom sector did not grow rapidly. A few firms were established in this period mainly by engineers experimenting with new designs (Lyons, 1977, p 116). There were 2400 power looms in 1813 (Baines, 1835, p. 235).

average speed of about 130 picks per minute. Further improvements raised the average speed to 200 by 1860 (Lyons 1977, p. 181).

Economics of the Power Loom and its Invention

The power loom was an impressive achievement that required ingenuity and persistence to develop. The fundamental question is: Why was the power loom invented in England at the beginning of the nineteenth century? The inventors (developers) had to set the costs of developing the power loom against the income from operating it. The costs depended on how much development work they had to do, that is, how good the machine had to be in order for the value of the cloth to cover the costs. For Horrocks, a speed of 35 picks per minute was good enough. The development costs would have been far higher if a loom had had to reach 100 picks per minute to turn a profit. Higher development costs would have reduced the likelihood of invention. I will argue that the power loom was developed to the point of commercial use in England around 1800 because the high wages earned by weavers lowered the break even speed of the machine to 35 picks per minute. If weavers had not earned high rents, it would have been necessary to develop a faster machine, and that would have been a more expensive R&D project. Likewise, in other parts of Europe where wages were much lower, much faster machines would have had to be developed before they could be commercially used, and that would have retarded invention.

Figures 3-6 summarize the argument. In 1780 a hand loom was the only way to weave cotton cloth, and it is represent as a single point in Figure 3. It was the least cost technique whatever the relative factor prices, as indicated by two iso-cost lines representing a high and a low wage relative to the price of capital services. The power loom represented a substantial increase in the capital-labour ratio (Figure 4). It cut costs in the high wage situation but not in the low wage situation. One interpretation of Figure 2 is that the high wage situation represents the high wages of weavers in 1793-1817, while the low wage isocost line represents the earlier situation before weavers earned high rents.

Figure 5 adds a line running from the power loom isoquant towards the origin. It represents the trajectory of improvements made by inventors and businessmen after the power loom came into commercial use (David 1975). The point where this line intersects the isocost line for the low wage situation is a tipping point, for the power loom had then been improved enough for it to be the least cost technique in the low wage situation. While the point (L*, K*) represents the degree of efficiency need for the power loom to be commercially profitable during the Golden Age, the tipping point indicates the higher degree of efficiency that would have been required for commercial operation, had the Golden Age not occurred.

Figure 6 adds a dotted line between the power loom isoquant and point C. The latter represents Cartwright’s first design for a power loom. It did not pay at any factor prices. The dotted line between C and P represents the improvements effected by Cartwright, Horrocks and others that turned the power loom from an R&D project into a machine that was commercially viable. Had this R&D project been undertaken in the low wage situation, the R&D trajectory would have been longer since the loom would have had to be perfected to the design at the tipping point. (This additional R&D is represented in Figure 6 by the double line between the power loom isoquant and the tipping point.) The R&D project would have been more substantial and more costly, so the likelihood of its being carried out would have been less.

I will develop this argument numerically by computing the cost per piece of printer’s cloth woven on power looms of various technical specifications and comparing those costs to the cost of hand woven cloth. I focus on the period 1800-17, which was the golden age of the handloom weaver as well as the period when the key investment decisions was taken by Horrocks and others. Costs are evaluated with average prices, wages, and earnings over this period. I assume that power looms had an economic life of ten years since most of the capital expenditure consisted of machinery.

Costs and revenues for these calculations are derived mainly from Lyons's (1977) remarkable Ph.D. dissertation. Lyons developed the costs for a model cotton mill with a 10 horsepower steam engine, which was the minimum efficient size. This implied a mill of 100 looms since each loom required 1/10 horsepower. Lyons worked out the design and costs of the mill for each year from 1815 to 1852. He specified the required warping, winding, and looming machines as well as dressing machines once they were invented. Using firm accounts and industry manuals, Lyons found the numbers and costs of the machines and the attendant workforce. These numbers changed as the technology advanced. Lyons also estimated associated costs like the coal burnt in the steam plant, flour used for sizing, lubricants, various overheads, inventories and so forth.

Technology improved over time, and Lyon's aim was to compute the profitability of building a weaving mill using the prices and best practice technology for each year from 1815 to 1852. My objective is different. I use the information to compute the profitability of using different technical designs with the prices prevailing in 1800-17.

Two developments in the early nineteenth century had major impacts on the cost of power loom weaving. First, faster operation led to lower costs since many components of cost–including many of the labour and capital expenditures–were independent of the rate of production. Second, the dressing machine, invented in 1803, cut costs at all production rates. Figure 7 shows average total cost curves for a piece of printer's cloth woven by machine. The decline with speed was substantial and the cost curve for a mill with a dressing machine lay below the cost curve for one without it.

The dressing machine contributed to the profitability of the power loom. Figure 7 shows how. Consider the high price of 300 d/piece that prevailed during the Golden Age of the handloom weaver. Without a dressing machine, Horrocks' 35 pick per second loom would not have covered its cost, which the model predicts would have been 320 pence. More R&D would have been required before the power loom could have been profitably used (i.e. Horrocks or someone else would have had to spend further sums perfecting the machine without receiving any immediate return from its use). Commercial operation would have required the machine to have been improved to the standard of 1810 before it would have covered its costs. Seven more years of experience would have been required.

When Horrocks' loom was used in combination with a dressing machine, however, it became commercially viable in its more primitive form. The cost model implies that Horrocks' loom, used in conjunction with a dressing machine, could undercut the handloom with a speed of 33 picks per minute. In fact, Horrock's loom made the transition from R&D to commercial application using the dressing machine with a speed of 35 picks per minute, and that close correspondence is evidence in favour of the model.

More primitive versions would not have paid. With a speed of 30 picks per minute, the cost model implies that unit costs would have been 341 pence per piece, which greatly exceeded the 300 d that handloom weaving entailed. The improvements Horrocks effected in the power loom between 1795 and 1803 raised its efficiency enough to transit into commercial profitability when it was combined with Johnson's dressing machine.

These results are contingent on the exceptional features of the years 1800-17, namely, the high wages earned by handloom weavers and the high prices received for cloth. These were two sides of the same coin since the wage of the handloom weaver equalled the price of the cloth less the yarn, capital, and labour used in its production. The high prices and wages were themselves the result of the boom in the cotton industry set off by the invention of spinning machinery. The high prices not only led to great prosperity and expansion of the cottage sector but also precipitated its demise by increasing the return to mechanization. We can see this by recomputing the return to installing power looms under a counterfactual scenario. The counterfactual is that spinning machinery did not create a boom in which handloom weavers received exceptional earnings. Around 1770 (before the boom), they only earned 70% as much as building labourers. We can ask what the return to power weaving would have been had they continued to earn 70% of the wage of a building labourer, had they, in other words, earned no rents from 1793 to 1817, or, to put it differently, had the golden age of the handloom weaver never taken place.

To compare hand and machine costs, we need to know what the price of printer's cloth would have been had handloom weavers earned 70% of the building labourer's wage from 1793 to 1817. The price can be computed from equation 1 by reversing the earlier calculation and solving for the price by substituting 70% of the labourer's wage. This change would have cut the price of cloth from 300 pence per piece to 245 pence per piece. Figure 7 shows that the power loom without a dressing machine could have undercut the handloom in this situation only if its speed exceeded 80 picks per minute. This level of efficiency was not reached until 1822 with Robert's loom. The situation would have been easier with the dressing machine since the break even speed would have been about 70 picks per minute. This rate was not achieved until just before Robert's improvements. A large amount of learning by doing occurred between the years that Horrocks' machine came into commercial use and the manufacture of these improved designs. In the absence of the 'golden age of the handloom weaver' the invention of the power loom would have been more expensive as a higher standard of performance would have been required to cross the threshold to commercial viability. Who would have financed all of the extra R&D to reach the higher standard? The conclusion must be that the invention of the power loom might never have happened in the absence of the golden age of the handloom weaver.[15]

History performed a natural experiment that confirms this claim. There was a substantial linen industry in Ulster in the nineteenth century. Spinning flax by machine was a difficult challenge that was not met until 1825. However, the power looms that wove cotton

---

[15] Von Tunzelmann (1978, pp. 196-202) compared the profitability of weaving 5/4 56-reed cambric in the mid-1830s by hand and by machine and concluded that hand weaving was still competitive. In von Tunzelman's view, the power loom became cheaper only when high pressure steam engines cut power costs in the 1840s. Lyons (1987) disputed this conclusion. His most telling objection was that von Tunzelmann assumed one loom per weaver rather than two. Von Tunzelman (1995, p. 15n3) acknowledged that Lyons had refined the data but remained unconvinced that two looms per weaver was correct. Exact comparison with my results is not possible since I analyse a finer cloth than cambric. However, perhaps because I rely on Lyons' data, my results are more in line with his position. Once Robert's loom was invented in 1825, the power loom was the least cost production technology across most fabrics. Alternatively, power looms in the mid-1830s achieved speeds close to 100 picks per minute, which would have made them the least cost technology (by my calculations) whether a weaver operated one loom or two.

cloth could weave linen with only minor modification.[16] Yet the power loom was not used to weave linen in the 1840s–by which time it had driven cotton handloom weavers out of business in Britain. Irish linen was still woven by hand. Ulster was so integrated with Britain in so many ways that one cannot explain the persistence of hand weaving in terms of political institutions, culture, lack of information, stature of the population, unavailability of equipment, etc. The big difference between Ulster and Britain was the lower wage level in Ireland. It was not profitable to mechanize spinning when labour was so cheap. The death and immigration triggered by the Famine in the 1840s changed the situation dramatically. The decline in the labour supply led to a rise in wages in the 1850s. Power weaving took off.

> So long as a man's labour could be had at the hand-loom in Ireland for a shilling a-day, it was felt no power-loom could work much, if at all cheaper; but when wages; some few years back, began to advance, and the population to decrease instead of increase, it was admitted that the power-loom was at length required. At present, one of the striking features in the linen trade is, the gradual introduction of power-looms for weaving the coarser qualities of cloth. (Charley 1862, p. 88).

The natural experiment of the Famine shows the sensitivity of adoption to the wage level.[17] Even without the Famine, Ulster manufacturers would have eventually adopted the power loom, just as Indian entrepreneurs have done. But the loom would have had to have been improved to a standard not reached until much later. If we imagine inventors like Horrocks contemplating the improvement of the power loom under pre-Famine Irish conditions, it would have seemed to them a pointless project since a late nineteenth century vintage loom would have been beyond their grasp at any conceivable cost.

Conclusion

The Industrial Revolution was one blast of Schumpeter's gale after another. Together they created an intertwined pattern of progress and poverty. Hobsbawm remarked that "Whoever says Industrial Revolution says cotton," and we can trace the gale through the textile industry.

The story begins around 1500 in the wool industry. Britain had an abundance of high quality wool, and the industry expanded four fold in the next 250 years. This required an increase in the number of spinners that greatly exceeded the growth in population. The work was done by women in their cottages, and by 1770, the industry employed most of the women in the country. As employment expanded, so did spinners' earnings. The irony is that when the cottage mode of production was at its zenith, it self-destructed. The high

---

[16] Linen yarn is less elastic than cotton, and a small vibrating roller was added to the loom to reduce strain on the yarn. (Charley 1862, p. 90-1) The linen looms were also built more robustly than the cotton looms.

[17] However, James (2004) has argued that the pace of adoption, once it started, was slow since there were further technical adjustments needed to make the power loom profitable in all circumstances.

wages earned by women in the eighteenth century meant that even inefficient machines like the first proto-types of Hargreave's jenny and Arkwright's water frame covered their costs. That would not have been the case in the seventeenth century when wages were lower, nor was it the case in the eighteenth in most other countries of the world. The fact that inefficient machines could be operated commercially meant that the R&D problem was a relatively simple one, and that is why a Hargreaves and an Arkwright tackled it when and where they did.

Once these machines came into use, the factory mode of production took off. The price of yarn fell so steeply that women stopped spinning in their homes. The factory mode of production destroyed the cottage mode and created large scale technological unemployment for the first time. Men had to support their families without the earnings of their wives–the male breadwinner family was born. The earnings of agricultural labourers were inadequate to keep their families at a respectable level with a diet of white bread, beef, and beer. Instead, they ate potatoes and porridge. The political discourse referred to the poverty of the farm labourer and the burden he placed on the poor law. Certainly the agricultural labourer's earnings were inadequate, but the underlying cause was not the high birth rate that the Malthusians gestured to; rather, it was technological change in the textile industry that put many wives and mothers out of work. In the 1820s, William Cobbett (1967, p. 131) observed that "A part, and perhaps a considerable part, of the decay and misery of this place [Whitington, Glos.] is owing to the use of *machinery*...in the manufacture of blankets, of which fabric the town of Witney...was the centre, and from which town the wool used to be sent round to, and the yarn, or warp, come back from, all these Cotswold villages,...This work is all now gone, and so the women and girls are a 'surplus *popalashon, mon*'".

The factory production of cotton yarn gave the cottage mode of production a new lease on life, but this time for men. The great growth in the supply of cheap yarn led to a rapid growth in demand for weavers. As their numbers expanded, so too did their wages. By the early nineteenth century, one in ten British men were weaving cotton, and in this golden age they earned double or triple what a labourer earned.

Then, as with the spinning sector, the high wages earned by hand loom weavers led inventors to develop the power loom to economize on their labour. The rents they earned meant that less efficient machines could cover their costs than would have been the case in other times and places. As a result, the profitability of invention was at its height, and the power loom came into commercial use.

While the invention of the power loom (like the spinning machines) was the result of high wages, the new technology led to poverty as the fall in the price of cloth drove the earnings of hand loom weavers down to bare bones subsistence. The 'standard of living issue' in the Industrial Revolution was the result of the destruction of hand loom weaving and other hand trades. Figure 10 makes the point. It shows the history of the real wages of building labourers, farm labourers, and hand loom weavers in Lancashire. At the outset, around 1770, their weekly earnings were similar. In the next 90 years, the earnings of hand loom weavers lept up and then collapsed. The real earnings of farm labourers changed little, while the earnings of building labourers steadily increased. By the middle of the nineteenth century, the building labourers earned three to four times as much as the hand weavers. The 'standard of living' issue was the result of this great growth in wage inequality.

Table 1

The diffusion of the power loom in Britain (benchmark dates)

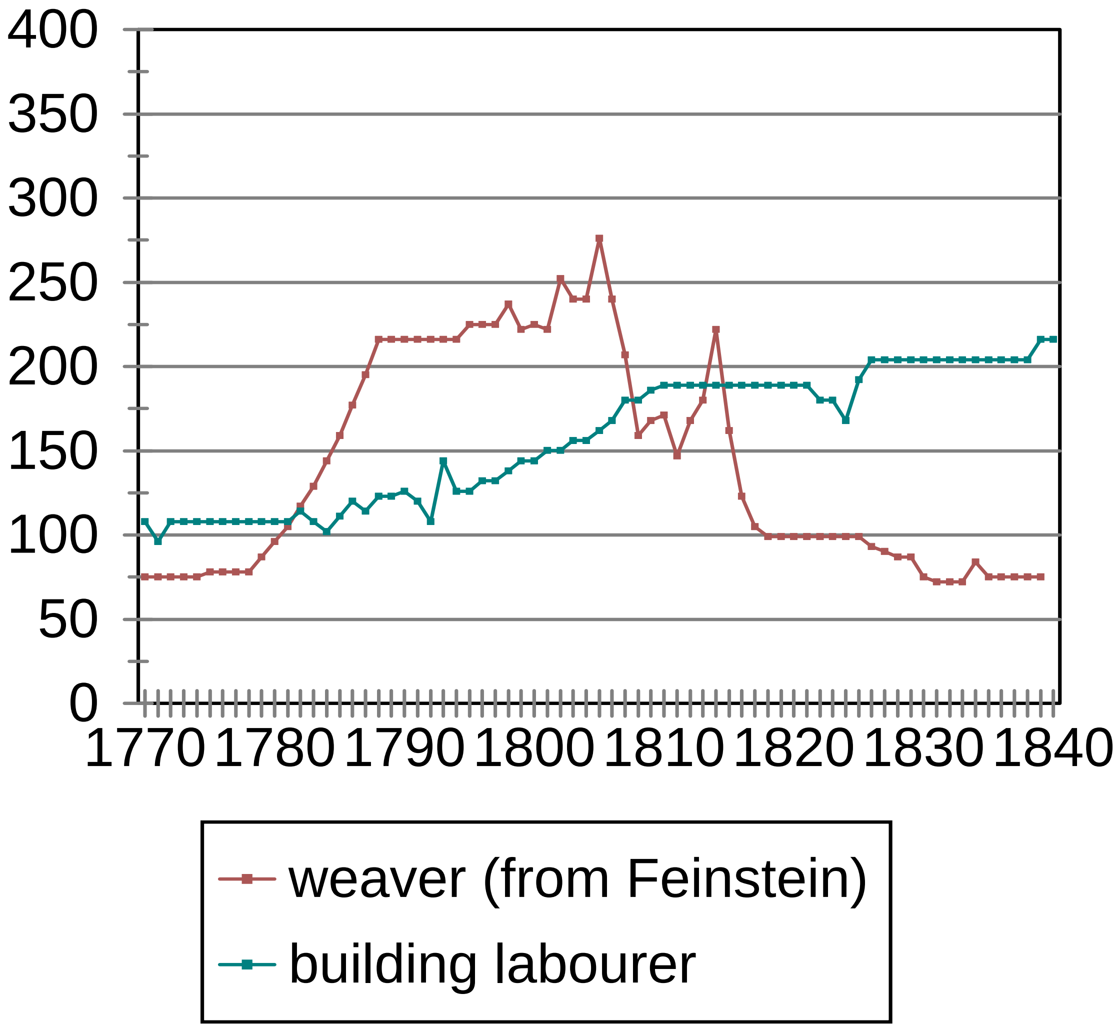
	number of handloom weavers & handlooms	number of power looms	Percentage Of cloth Woven by power
1780	37,000		
1792	95,000		
1806	184,000	Hundreds	0%
1812	208,000	2,400	1%
1820	240,000	14,150	10%
1832	227,000	100,000	55%
1835	188,000	108,894	71%
1845	60,000	225,000	95%
1850	43,000	249,627	97%
1860	10,000	400,000	100%

sources:
production by hand and by power-this was estimated in steps. First, British consumption of raw cotton(or retained imports before 1811)from Mitchell and Deane (1971, pp. 177-9)was multiplied by 14.5/16 to estimate British production of cotton yarn. Second, exports of yarn were subtract from this to compute domestic consumption of yarn. This was then multiplied by .94, the share of yarn woven into cloth rather than used for lace or hosiery (calculated from Baines 1835, pp. 345, 406-438, Ure 1836, Vol. II, p.319). Fourth, for 1812-32 the quantity of yarn woven by power looms was estimated by the number of looms (above) multiplied by output per loom from Ellison (1886, pp. 68-9) and Wood (1903, p. 302), intervening years interpolated Fifth, for 1812-1832 power loom processed yarn was subtracted from total yarn woven to compute hand loom processed yarn. Sixth, for years after 1832, yarn woven by hand estimated as the number of workers above multiplied by 300 lbs per year. Power loom production computed as total yarn woven minus handloom processed yarn.
number of handloom weavers
1806ff Wood (1910, pp. 588-9).
For the period 1785-1832, the number of handloom weavers was computed from the estimate of yarn woven by hand by dividing by output per worker taken to 300 lbs per year. (Prior to 1785, output per worker taken to be 150 lbs per year on the assumption that the warps were linen.) The resulting series agrees well with Wood’s estimates for the period of overlap and with Feinstein’s estimates for earlier years. 1780 and 1792 values in table from these calculations.

Number of power looms-Baines (1835, pp. 235), Timmins (1993, p. 20), Wood (1903, p. 302).

Figure 1

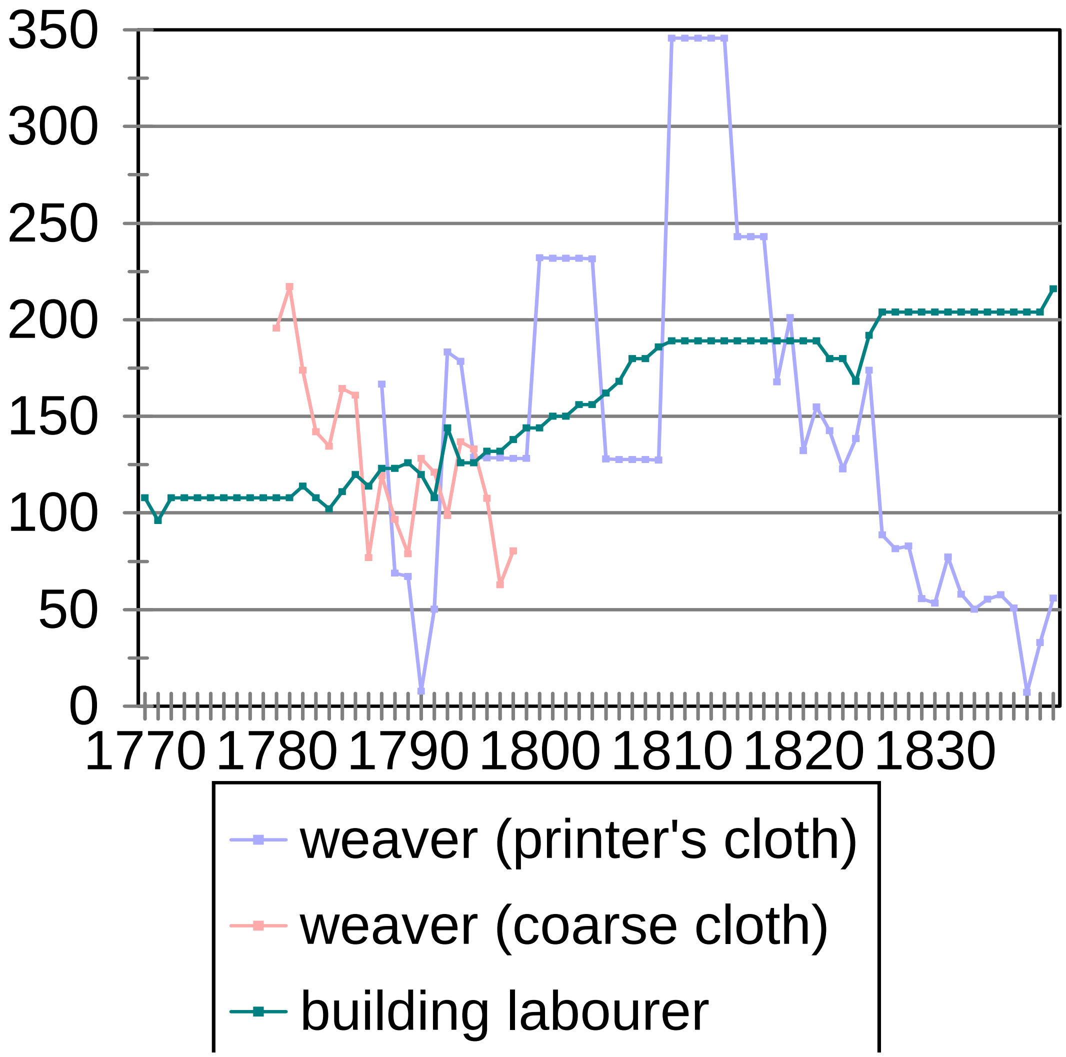
Weekly earnings (pence) of a hand loom weaver and a building labourer



sources:
hand loom weaver–Feinstein's index based on Bowley, Palgrave, and Wood as described in Feinstein, (1998, p. 189).
building labourer–1700-94: Gilboy, *Wages*, pp.280-2. 1810-25: *Tables of the revenue*, p. 165. 1839-1900 Bowley (1900, pp. 310-11).

Figure 2

Computed weekly earnings (pence) of hand loom weavers from different cloths



See text

Figure 3

Isoquant of hand loom

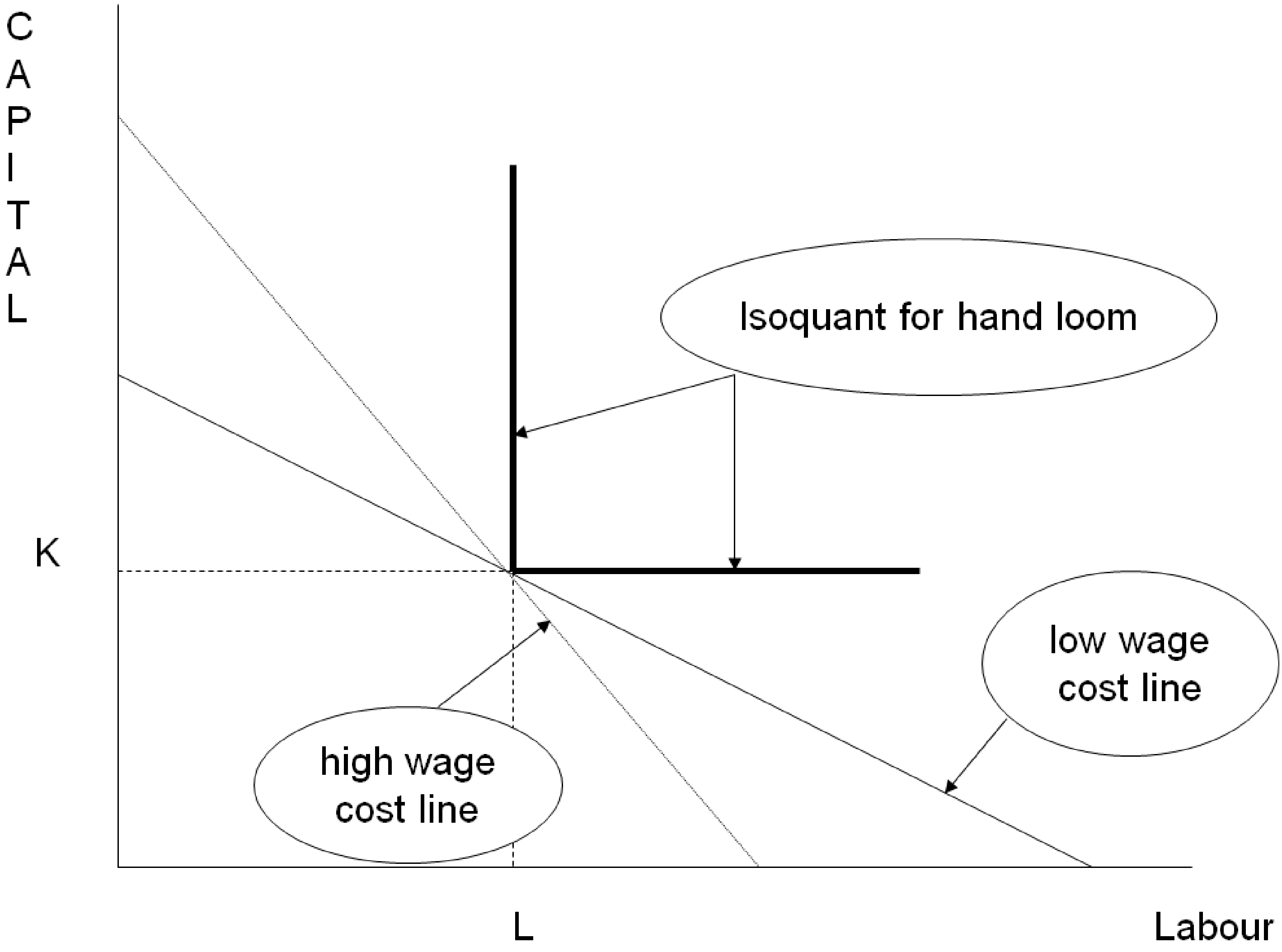


Figure 4

hand loom and power loom isoquants

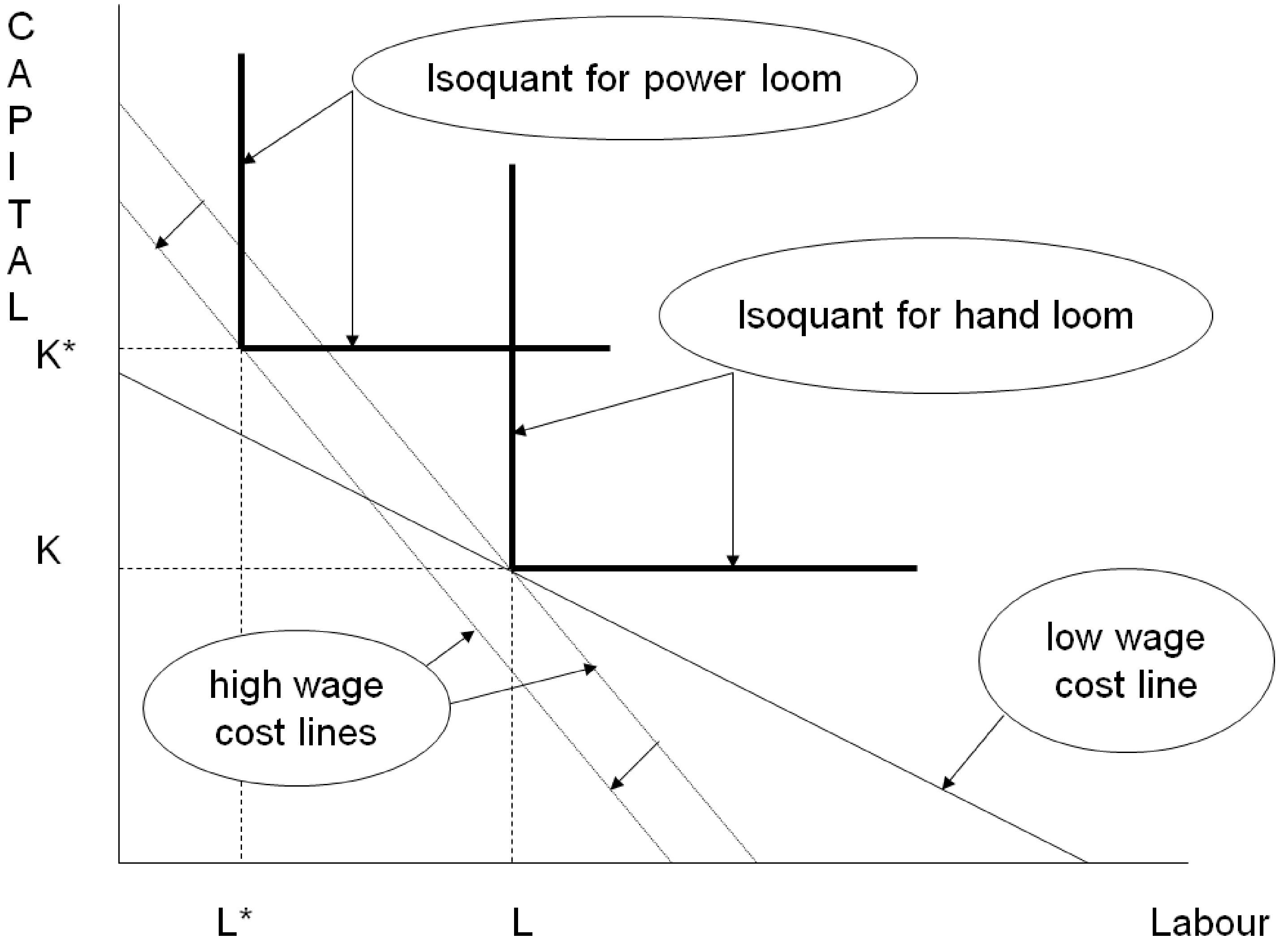


Figure 5

The Trajectory of Improvements and the Tipping Point

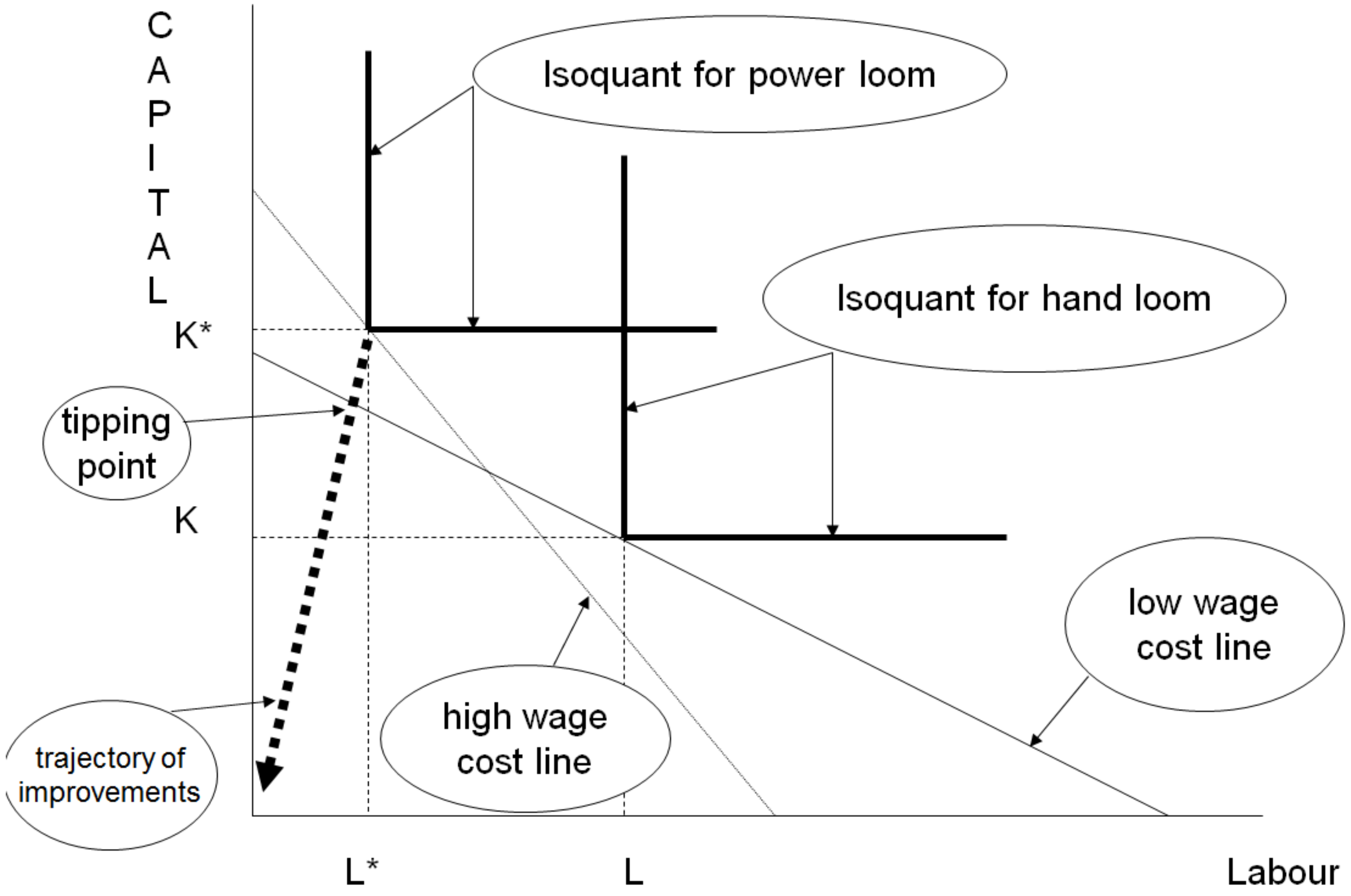


Figure 6

Trajectory of improvements during R&D

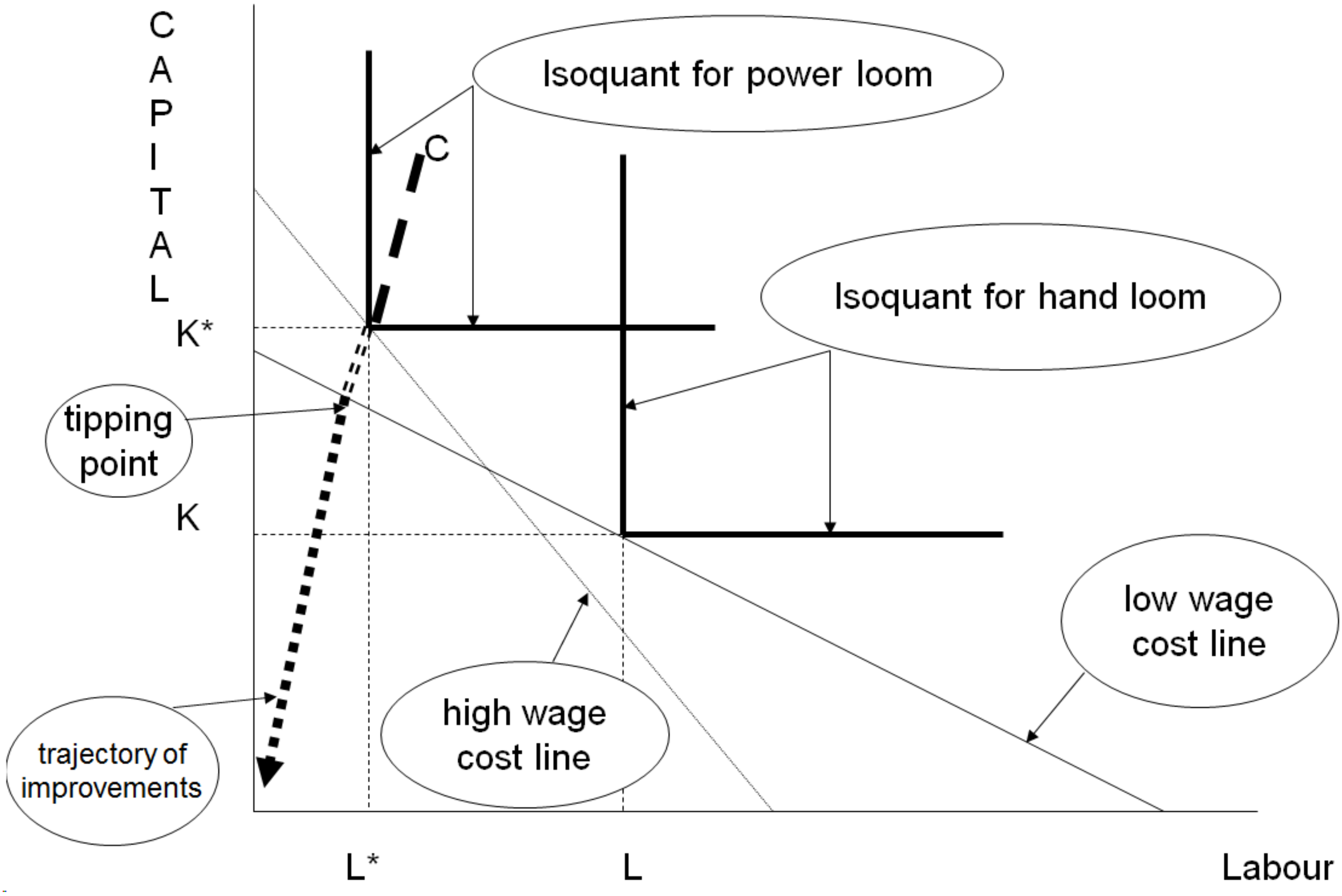


Figure 7

weaving cost (pence per piece)

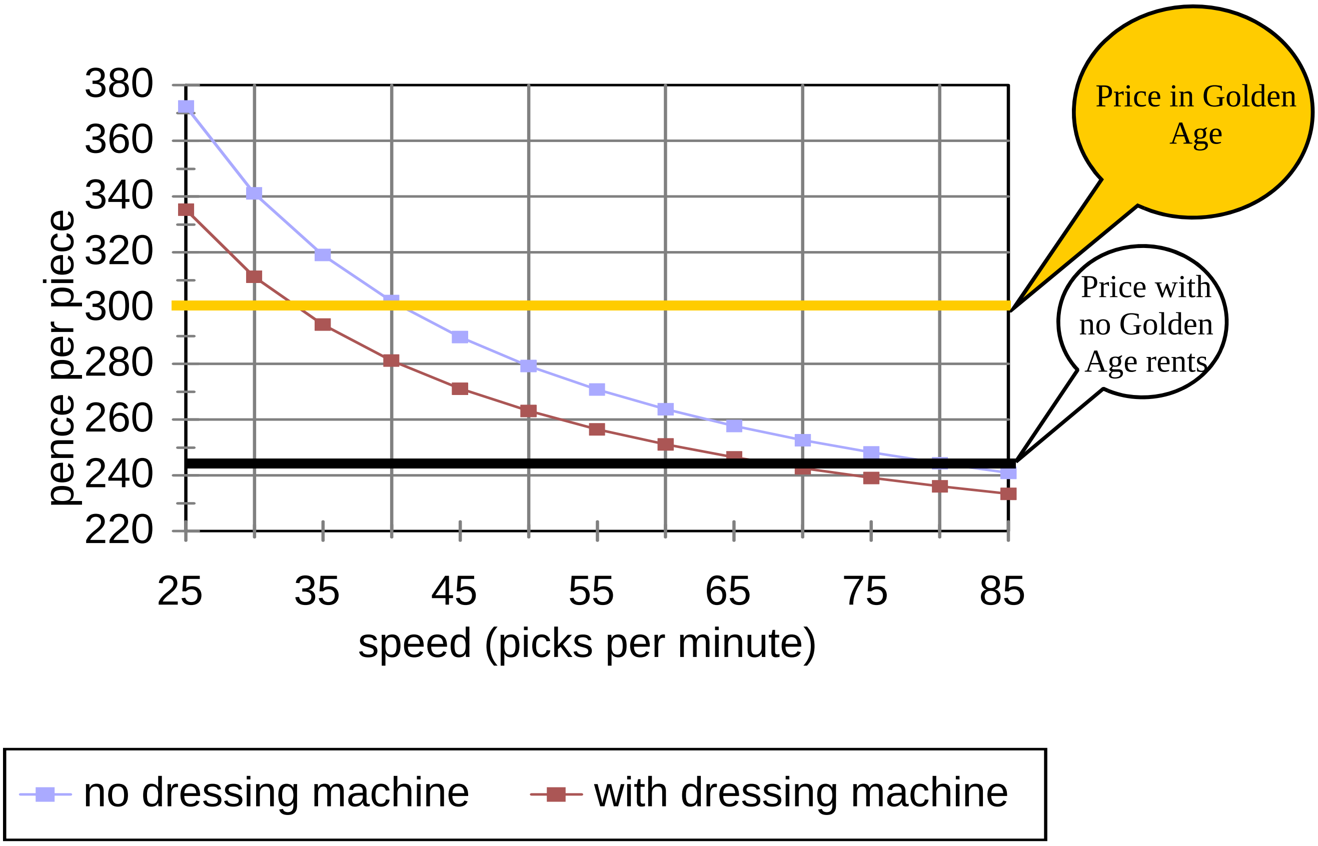
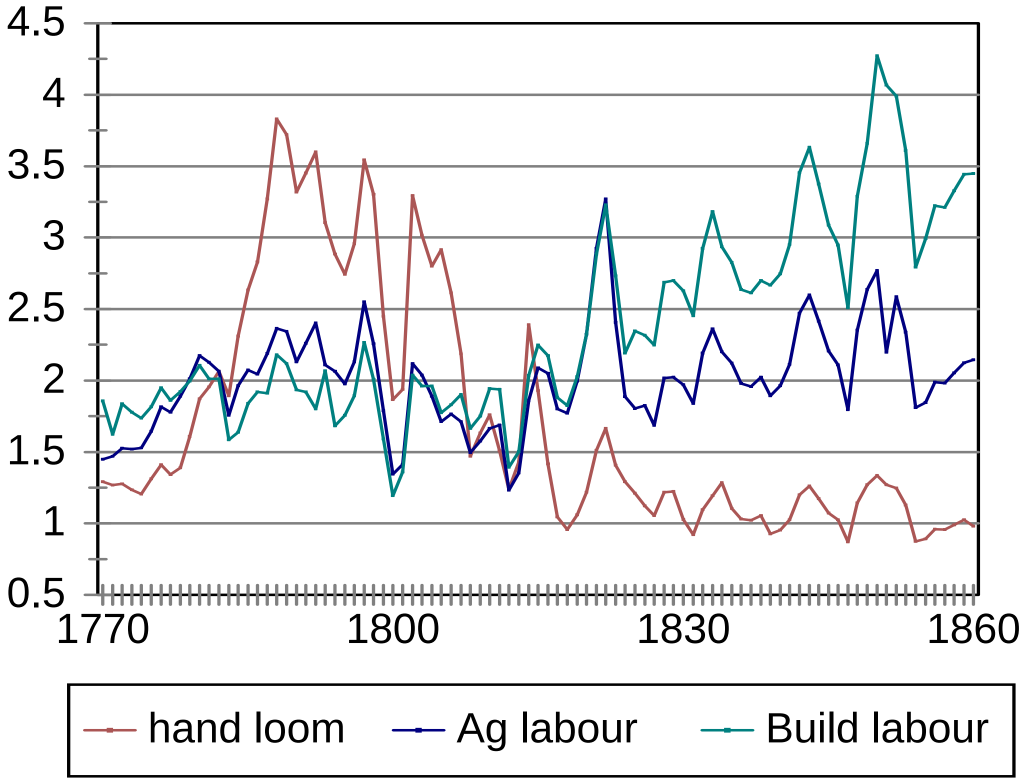


Figure 8

Wage Inequality in Lancashire
(1 = bare bones subsistence)



sources:
hand loom weaver–see Figure 1
agricultural labourer–Bowley, (1898, p. 720). Wages implied by Bowley's index numbers.
building labourer–see Figure 1.
These nominal wage series were deflated by the subsistence price index described in Allen (2014).

Appendix: Profitability model for Neild cloth

output

pieces per year = 100 looms x 50 weeks/yr x hrs/wk /(hrs/piece)

hrs/piece = 87696 picks per piece / (effective pick rate per minute * 60)

costs

yarn

yarn cost per year (£) = output * yarn cost per piece / 240

yarn cost per piece (d) = 189.2669
= 2.215 lb/piece * price warp + 2.415 lb/piece * price of weft

The calculations require the prices of 36 count warp and weft yarn. Lyons (1977, p. 199) presents estimated time series from 1818 onwards. Earlier years were deduced from Harley (1998, p. 68), who presents the cost of cotton in calico and the value added in producing the warp and the weft.

coal

coal cost per year (£) = coal cost per piece (d) * pieces per year / 240

coal cost per piece (d) = 3.32
= price of coal per lb (d) * lbs of coal per HP-hr * HP-hr per piece

horse-power hours per piece = hours per piece /12

See Lyons (1977, p. 185). Coal price from von Tunzelman (1978, p. 96) for Manchester in 1803.

flour

flour cost per year (£) =flour cost per piece (d) * pieces per year/240

flour cost per piece (d) = 1.51 = price of flour per lb (d) * 0.5 lbs per piece

source: Lyons (1977, pp. 195, 200). Flour price is from Greenwich hospital from Beveridge (1965, p. 291).

production labour

labour cost per year (£) = labour cost per piece (d) * pieces per year/240

labour cost per piece (d) = sum of cost per piece for winding (3 d), warping (0.5 d), looming

(0.75 d), overseeing (2.6 d), dressing, and weaving.

labour cost of dressing = 4.65 if there is a dressing machine and 0 if no dressing machine

labour cost of weaving = wage per week (d) / pieces per weaver per week

pieces per weaver per week = pieces per loom per week * looms per weaver

pieces per loom per week = pieces per year/ (100 looms * 50 weeks/year)

looms per weaver = 2 if there is a dressing machine and 1 if no dressing machine

Except for weaving, labour cost per piece from Lyons (1977, p. 212) for 1818. For weaving, unit labour cost per piece was computed from the weaver's wage rate of 11 shillings per week as 12 pence per shilling *11 shillings per week/pieces per weaver per week. Production labour expenses were extrapolated back in time with wage series of women employed as tenters and throstle spinners since most production workers in cotton weaving mills were women. See Feinstein (1998, p 190), for throstle spinners and Bowley (1900, p. 199 facing) for women as tenters.

<u>overhead labour</u>

1 book keeper @ 324 d/wk
1 engineer @ 324 d/wk
3 mechanics @ 172 d/wk
1 watchman @ 195 d/wk
1 size maker @ 174 d/wk
1 sweeper @ 87 d/wk
4 warehousemen @ 114 d/wk

The wage rates shown are for 1818. Wages were projected to earlier years using the wage rate of labourers in Lancashire as an index.

Lyons (1977, p. 211, 213, 231n3).

<u>overhead expenses</u>

87.5 gallons olive oil = £91.25
100 shuttles = £20
100 healds & staves = £20
100 reeds = £20
400 pickers = £8.3
300 lbs leather straps = £37.5
75 cleaning brushes = £3

The total of these expenses was multiplied by two to account for 'other costs'. Lyons (1977, pp. 214, 215, 219)

Interest on working capital

interest per year (£) = ..1*.34 * annual revenue

This is Greg's accounting using a high interest rate closer to the opportunity cost of capital (Lyons 1977, pp. 103n11, 227).

investment in fixed capital

100 power looms @£16.5 = £1650
Installation of power looms = £202
4 dressing machines @ £50 = £200
120 spindles of winding frames @ 6s = £36
1 warp mill @ £16 = £16
2 looming frames @ £2 = £4
additional machinery investment = 9% of cost of machinery other than looms = £23.04
steam engine = £750
shafting = £275
mill = £1400

total fixed investment = £4531.04

Lyons (1977, pp. 188-193, 216-230). Capital goods prices were unchanging from 1800 onwards, which is the period when the investment decisions were taken (Feinstein 1988, pp. 431, 441).

Capital using costs

These costs were computed as the interest on working capital plus fixed investment multiplied by the supply price of capital and the depreciation rate. The depreciation rate was taken to be 10%. The supply price of capital was set at 15%. Harley (2010) found that the return on to capital in the cotton textile during the Industrial Revolution was about 13%, and Hudson (1986, pp. 235-41, 272, 277) calculated the profit rate on business capital to have been about 14% in the wool industry in the 1850s.

References

Acemoglu, Daron (2002a). “Technical Change, Inequality, and the Labor Market,” *Journal of Economic Literature*, Vol. 40, No. 1 (Mar., 2002), pp. 7-72

Acemoglu, Daron (2002b). “Directed Technical Change,” *The Review of Economic Studies*, Vol. 69, No. 4 (Oct., 2002), pp. 781-809.

Acemoglu, Daron (2003). *Knowledge, information, and expectations in modern macroeconomics : in honor of Edmund S. Phelps*, ed. by Philippe Aghion, Roman Frydman, Joseph Stiglitz and Michael Woodford, Princeton, NJ ; Oxford : Princeton University Press.

Acemoglu, Daron (2010). “When Does Labor Scarcity Encourage Innovation?” *Journal of Political Economy*, Vol. 118, No. 6 (December 2010), pp. 1037-1078

Acemoglu, Daron, and Restrepo, Pascual (2017). “The Race Between Machine and Man: Implications of Technology for Growth, Factor Shares and Employment,”

Acemoglu, Daron, and Robinson, James A. (2012) *Why Nations Fail: The Origins of Power, Prosperity, and Poverty*, New York, Crown Publishers.

Aghion, Philippe, Antoine Dechezlepretre, David Hemous, Ralf Martin, John Van Reenen (2016). “Carbon Taxes, Path Dependency, and Directed Technical Change: Evidence from the Auto Industry,” *Journal of Political Economy*, vol. 124, pp. 1-51.

Allen, Robert C. (2009). “Engel’s Pause: Technical Change, Capital Accumulation, and Inequality in the British Industrial Revolution,” *Explorations in Economic History*, Vol. 46, Number 4, pp. 418-35.

Allen, Robert C. (2015). “The High Wage Economy and the Industrial Revolution: A Restatement,” *Economic History Review*, Vol. 68, No. 1, pp. 1-22.

Allen, Robert C. (2017). *The Industrial Revolution: A Very Short Introduction*, Oxford, Oxford University Press.

Amalsad, D.M. (1951). *Cotton Hand Spinning*, Calcutta, Orient Longmans Ltd.

Amalsad, D.M. (1961). *Yarn and Cloth Calculation*, Calcutta, Orient Longmans Ltd, revised edition.

Baines, Edward (1835). *History of the Cotton Manufacture in Great Britain*, London, H. Fisher, R. Fisher, and P. Jackson.

Bowley, A. L. (1898). ‘The Statistics of Wages in the United Kingdom During the Last Hundred Years. (Part I.) Agricultural Wages,’ *Journal of the Royal Statistical Society*, Vol. 61, pp. 702-722.

Bowley, A.L. (1902). “The Statistics of Wages in the United Kingdom During the Last

Hundred Years: Wages in the Worsted and Woollen Manufactures of the West Riding of Yorkshire," *Journal of the Royal Statistical Society*, Vol. 65, pp. 102-26.

Bythell, Duncan (1969). *The Handloom Weavers: A Study in the English Cotton Industry during the Industrial Revolution*, Cambridge, Cambridge University Press.

Charley, William (1862). *Flax and its Products in Ireland*, London, Bell and Dalby.

Clark, Gregory (2007). *A Farewell to Alms: A Brief Economic History of the World*, Princeton, Princeton University Press.

Clark, W. A. Graham (1908). *Cotton Textile Trade in Turkish Empire, Greece, and Italy*, Washington, Government Printing Office.

Cobbett, William (1967). *Rural Rides*, ed. by Asa Briggs, Everyman's Library, London, J.M. Dent & Sons, Ltd.

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

Ellison, Thomas (1886). *The Cotton Trade of Great Britain*, London, Effingham Willson, Royal Exchange.

Feinstein, Charles H. (1998). "Wage-Earnings in Great Britain During the Industrial Revolution," in *Applied Economics and Public Policy*, ed. By Iain Begg and S.G.B. Henry, Cambridge, Cambridge University Press, pp. 181-208.

Habakkuk, H. J. (1962). *American and British technology in the nineteenth century : the search for labour-saving inventions*, Cambridge, Cambridge University Press

Hammond, J.L. and Hammond, B (1919). *The Town Labourer: 1760-1832*, London, 4th impression.

Hanlon, W. Walker (2015). "Necessity is the Mother of Invention: Input Supplies and Directed Technical Change," *Econometrica*, Vol. 83, pp. 67-100.

Harley, C.K. (1971). "The Shift from Sailing Ships to Steam Ships, 1850-1890: A Study in Technological Change and its Diffusion," in *Essays on a Mature Economy: Britain after 1840*, ed. by D.N. McCloskey, Princeton, Princeton University Press, pp. 215-34.

Harley, C.K. (1973). "On the Persistence of Old Techniques: The Case of North American Wooden Shipbuilding," *Journal of Economic History*, Vol. 33, pp. 372-98.

Harley, C.K. (1998). "Cotton Textile Prices and the Industrial Revolution," *Economic History Review*, Vol. 51, pp.49-83.

Harley, C. Knick (2010). "Prices and Profits in Cotton Textiles during the Industrial

Revolution," Oxford University, Working Papers in Economic and Social History, No. 81.

Hayami, Yujiro, and Ruttan, Vernon W (1971). *Agricultural development : an international perspective*, Baltimore, Johns Hopkins University Press.

Hicks, John (1932). *The theory of wages*, London, Macmillan.

Hudson, Pat (1986). *The Genesis of Industrial Capital: A Study of the West Riding Wool Textile Industry, c. 1750-1850*, Cambridge, Cambridge University Press.

Hunt, David (2004). 'Cartwright, Edmund (1743–1823)', *Oxford Dictionary of National Biography*, Oxford University Press, 2004; online edn, Oct 2007. [http://www.oxforddnb.com/view/article/4813, accessed 25 Aug 2013]

Hyde, Charles K. (1977). *Technological Change and the British Iron Industry, 1700-1870*, Princeton, Princeton University Press.

India (1942). *Report of the Fact-Finding Committee (Handloom and Mills)*, Calcutta, Government of India Press.

James, K. (2004). "The Handloom in the Ulster post-famine Linen Industry," *Textile History*, Vol. 35, pp. 178-191.

Kennedy, Charles, (1964). "Induced Bias in Innovation and the Theory of Distribution" *Economic Journal*, Vol. LXXIV, pp. 541-547.

Latif, Muhammad Abdul (1997). *Handloom Industry of Bangladesh, 1947-90*, Dhaka, The University Press ltd.

Lyons, J. (1977). *The Lancashire Cotton Industry and the Introduction of this Powerloom, 1815-1850*, Ph.D. dissertation, Department of Economics, University of California, Berkeley.

Lyons, J. (1987). "Powerloom profitability and steam power costs: Britain in the 1830s," *Explorations in Economic History*, Vol. 24, pp. 392-408.

Marx, Karl (1867). *Capital*, Vol. I, Moscow, Progress Publishers, first English edition, 1887, https://www.marxists.org/archive/marx/works/download/pdf/Capital-Volume-I.pdf Acessed 4 August 2017.

McCloskey, D.N. (1973). *Economic Maturity and Entrepreneurial Decline: British Iron and Steel, 1870-1913*, Cambridge, MA, Harvard University Press, 1973

Mitchell, Brian R., and Deane, Phyllis. (1971). *Abstract of British Historical Statistics*, Cambridge, Cambridge University Press.

Mokyr, Joel (2002). *The Gifts of Athena: Historical Origins of the Knowledge Economy*, Princeton, Princeton University Press.

Marsden, Richard (1895). *Cotton Weaving*, London, George Bell & Sons.

Newell, Richard G., Adam B. Jaffe, Robert N. Stavins (1999). “The Induced Innovation Hypothesis and Energy-Saving Technological Change,” *The Quarterly Journal of Economics*, Vol. 114,, pp. 941-975.

Neild, W. (1861). “An account of the prices of printing cloth and upland cotton from 1812 to 1860,” *Journal of the Statistical Society*, Vol. XXIV, pp. 491-7.

North, D.C. and Weingast, B.R. (1989). ‘Constitutions and Commitment: Evolution of Institutions Goverining Public Choice in Seventeenth Century England,’ *Journal of Economic History*, Vol. 49, pp. 803-832.

Nuvolari, A., and Verspagen, B. (2009). “Technical Choice, Innovation and British Steam Engineering, 1800-1850,” *Economic History Review*, Vol. 62, pp. 685-710.

O’Brien, Patrick (1997). “The Micro-foundations of macro-invention: The Case of Reverend Edmund Cartwright,” *Textile History*, Vol. 28, pp. 201-233.

Palgrave, R.H.I. (1926). *Palgrave’s Dictionary of Political Economy*, ed. by H. Higgs, London, Macmillan, second edition.

Radcliffe, William (1828). *Origin of the the [sic] new system of manufacture commonly called "power-loom weaving,"* Stockport, J. Lomax.

Popp, David (2002). “Induced Innovation and Energy Prices,” *The American Economic Review*, Vol. 92, pp. 160-180.

Samuelson, Paul, (1965). “A Theory of Induced Innovations Along Kennedy-Weisacker Lines,” *Review of Economics and Statistics*, Vol. XLVII, pp. 444-464.

Sandberg, Lars G. (1974). *Lancashire in Decline*, Columbus, Ohio State University Press.

Schumpeter, Joseph A. (1994). *Capitalism, Socialism, and Democracy*, London, Routledge, ebook.

Searby, P. (1972). *Weavers and Freemen in Coventry, 1820-1861: Social and Political Traditionalism in an Early Victorian Town*, University of Warwick, Ph.D. dissertation. http://wrap.warwick.ac.uk/3472/1/WRAP_THESIS_Searby_1972.pdf Acessed 6 August 2017.

Tables of the revenue, population, commerce, &c. of the United Kingdom and its dependencies. Part I. From 1820 to 1831, both inclusive, British Parliamentary .Papers, 1833, Vol. XLI.

Timmins, Geoffrey (1993). *The Last Shift: The Decline of Handloom Weaving in Lancashire*, manchester, manchrester University Press.

Timmins, Geoffrey (1996). "Technological Change," in Mary B. Rose, ed, *The Lancashire Cotton Industry: A History since 1700*, Preston, Lancashire Country Books, pp. 29-62.

Ure, Andrew (1836). The cotton manufacture of Great Britain, London, C. Knight.

von Tunzelmann, G.N. (1978). *Steam Power and British Industrialization to 1860*, Oxford, Clarendon Press.

Von Tunzelmann, G.N. (1995). "Time-saving technical change: the cotton industry during the Industrial Revolution," *Explorations in Economic History*, Vol. 32, pp. 1-27.

Voth, Hans-Joachim (2000). *Time and Work in England, 1750-1830*, Oxford, Clarendon Press.

White, George (1846). *A Practical Treatise on Weaving by hand and Power Looms*, Glasgow, John Niven.

Wood, G.H. (1903). "The Course of Women's Wages during the Nineteenth Century," in B.I. Hutchins, *A History of Factory Legislation*, Westminster, P. S. King & Son, Appendix A, pp. 257-316.

Wood, G.H. (1910). "The Statistics of Wages in the United Kingdom During the Nineteenth Century, Parts XV-XIX, the Cotton Industry," *Journal of the Royal Statistical Society*, Vol. 73, pp. 39-58, 128-63,283-315, 411-34, 585-626.