Creative Destruction or Destructive Creation?
A Prelude to the Industrial Revolution

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Joel Mokyr
Northwestern University and Tel Aviv University

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Introduction

The Industrial Revolution was the mother of all creative destruction. Before 1750, of course, there was plenty of technological progress, and some of it destroyed jobs — one thinks of the scribes and copyists displaced by the printing press. Yet it is clear that innovation before the Industrial Revolution was not powerful enough to make much of a dent at the very low rates of economic growth before 1800, and hence its power to be a major disruptor was equally limited. The Industrial Revolution changed all that. It did not invent invention per se, but as Alfred North Whitehead famously wrote, it invented the *method* of invention by realizing not just the potential of science as a "storehouse of ideas" but also coming up with the "imaginative designs" needed to bridge the gap between a scientific idea and production (Whitehead [1925], 1953, pp. 96-97). Creative destruction required original thinkers and the freedom to be a non-conformist, but it equally needed competent artisans to carry out the new designs. Invention led to creative destruction, but as I shall argue below, also to destructive creation, the price of progress.

Growth before the Industrial Revolution could of course be equally destructive. Much of it had the nature of "Smithian Growth" — essentially the gains from trade and specialization and the realization of comparative advantage. Trade and the realization that certain crops could be transplanted from area to area (resulting from the "Columbian Exchange") led to the prosperity of Britain and The Netherlands on the eve of the Industrial Revolution and to a host of new products being made available (see Nunn and Qian, 2010 for an excellent survey) — at a price. The horrid destruction that these voyages inflicted on non-European populations, some of it accidental through the spread of infectious disease, some of it intentional through the slave trade and slave-operated plantations, dwarfed any destruction that the technological creativity of the Industrial Revolution

inflicted on the populations of European economies.

In what follows, I propose to look at the sources of creative destruction during the Industrial Revolution. In previous work (Kelly et al. 2014, 2021; Mokyr, 2021) my collaborators and I have pointed to the origins of Britain's technological precocity in the eighteenth century. Aghion, Antonin and Bunel (hence AAB) touch upon the topic in their book: "The Industrial Revolution was an illustration of three fundamental principles of the paradigm of creative destruction, namely cumulative innovation…institutions [that] … foster innovation, and competition…" [p.39]. There is little to disagree with this statement, as long as we add one more element: mechanical competence.

Looking at the statement in the AAB book, it seems perhaps intuitively obvious that institutions would play a role in this transformation. But some of the most influential scholars in economic history have taken a skeptical view.[1] At the most basic level, the issue is quite simple: the literature that stresses institutions as a driver of economic growth focus on market-driven Smithian Growth, which needed peace, freedom, mobility, and a rule of law to thrive. The problem is that such growth runs into mercilessly sharp diminishing returns and cannot support sustained and continuous economic growth (Mokyr, 2018). Neither can capital accumulation. Only the expansion of useful knowledge can do that, even though there, too, it is often thought that opportunities are exhausted at various points.[2] It is far from clear what institutions foster and support creative destruction. Do they thrive primarily in a free-market and low-regulation environment in which competitive firms are free to experiment and in which "thinking outside the box" is not just tolerated but encouraged,

[1]McCloskey (2010, pp. 296-345; 2016) launches what is probably the most effective criticism of institutions as a factor in triggering economic growth. For a reply, see Greif and Mokyr (2016).

[2]The most extensive exposition of this argument is Gordon (2016). For a recent quantitative examination, see Bloom et al. (2020).

or do they need government funding and support of innovative firms and projects, as Mazzucato has insisted, and others have contested (Mazzucato, 2015; McCloskey and Mingardi, 2020). Is it even possible that authoritarian and repressive regimes such as the Soviet Union or contemporary China are capable of sustained creativity and innovation notwithstanding the absence of freedom? Is their creativity doomed if ~~individual freedom~~ and dissent are severely curbed?

The institutions that fostered creative destruction are above all required to do two things: provide incentives for the inventors and entrepreneurs, and make sure that they had the technical and financial wherewithal to carry out their designs. Yet, as many scholars starting from Greif (2005) and McCloskey (2021) have argued, institutions depend on a cultural underpinning that ensures that they will be effective. If society postulates rules that nobody takes seriously because they conflict with their deep beliefs or values, they will be hard to enforce unless applied with considerable coercive power. The institutions that drove technological progress in the eighteenth century rested on a set of cultural beliefs we tend to group under the umbrella term of "the Enlightenment," the central cultural development of the eighteenth century. Specifically, they rested on those elements in Enlightenment thought that addressed matters of material progress and the solution of technological issues through expanded useful knowledge. We thus speak of a "medical enlightenment" (Porter, 1982), an "agricultural enlightenment" (Jones, 2016) and an "industrial enlightenment" (Mokyr, 2009). Culture (what people believe and think they know) and institutions (the rules and customs that determine their incentives) co-evolve and affect one another in many complex ways (for a survey, see Alesina and Giuliano, 2015). In the era of the Industrial Revolution, the central cultural tenet that drove creative destruction was a firm belief in progress.

Institutions and the Industrial Revolution

The literature that links institutions to the Industrial Revolution has expanded quite a bit in recent years as a result of the influential work of Douglass North and other members of the neo-institutional school (Mokyr, 2008; Kapas, 2012). They can be roughly divided into two groups: those that focus on general political changes in Britain in the century before the advent of the Industrial Revolution, and those that focus on more specific institutions that affected incentives directly. The literature on the role of politics was launched in a seminal paper by North and Weingast (1989), which argued that the Glorious Revolution and the subsequent Bill of Rights, above all, shaped the English (and soon after the British) polity in a way that was conducive to economic development. They maintained that the system that emerged after the Glorious Revolution and the Bill of Rights in 1689 was one in which the British had made the government guarantee to its citizens that it would not tax them without Parliament's consent. In other words, it "pre-committed" to be constrained by Parliament. Pincus and Robinson argue that the Glorious Revolution once and for all determined the *de facto* rules by which political power was exercised: the emergence of parliamentary sovereignty meant that policy was henceforth set by political parties and thus ministers, and that the Whigs set an agenda of "economic modernization."

The difficulty with this approach is that it explains a polity that is more amenable to create "inclusive institutions," encourage trade, rationalize government, and set up more effective organzations such as the Bank of England. It is not one that is specifically friendly to creative destruction. It took another seventy years after the Bill of Rights for the wave of inventions we associate with the Industrial Revolution to start in earnest in the 1760s.

The best way to think of the "general institutions" argument is this: In the seventeenth

century, and specifically after the Glorious Revolution, England (and then Britain) "solved" the problem of *meta-institutions*. If institutions are the rules by which the economy operates, the higher-level question arises: what are the rules by which society makes the rules? The answer is that the rules are set by meta-institutions and that the effectiveness of society to set these rules depends on the legitimacy of the meta-institutions. In Britain the question was resolved peacefully and Parliament became "the place where absolute despotic power, which must in all governments reside somewhere, is entrusted," as Blackstone noted in 1765. While there was no guarantee that this would be *necessarily* good for economic growth, eighteenth century developments drove it in that direction. Moreover, in many countries, struggles over meta-institutions led to bloody revolutions, which then degenerated into military dictatorships and wars, as well as a reactionary backlash. Britain (excepting Ireland) was spared violent insurrections and upheaval even if a conservative backlash to what was happening in France did lead to a temporary political setback in the 1790s.

One important advantage was that Britain's Parliament was on the whole friendly to innovation and hostile to Luddite movements and other forms of resistance to technological progress. Almost everywhere in Europe innovation was resisted by vested interests and workers concerned about the effect of creative destruction on their employment and skills. In Britain, by and large, the government was not sympathetic to these movements and supported the industrialists, with force when needed. Parliament also created a mechanism for enclosures, which speeded up the re-organization of agriculture. Remarkably, violent resistance to eighteenth-century parliamentary enclosures was minimal.

Specific institutions have been suggested as important contributions to the Industrial Revolution. Of those, the most intuitive and seemingly persuasive is the English patent law, which

was passed in 1624 and was widely regarded at the time as a great advantage to Britain.[3] Modern economists, including AAB, have tended to agree (North and Thomas, 1973, p. 156; AAB, 2021, p. 37). Other contemporaries strongly disagreed.[4] A recent summary (Bottomley, 2014, p. 293) concludes that the patent system "made a signal contribution to technological development during the Industrial Revolution." But a closer examination of patents in the Industrial Revolution raises some legitimate concerns about the magnitude (if not the direction) of the effect. As a prime causal factor, ~~however,~~ it runs into a number of logical problems. First, the number of patents taken out is very small and shows no trend before the middle of the eighteenth century, when it suddenly surges upward. In other words, for more than a century, the system laid dormant; its sudden spike must have been driven by something else. Second, the Netherlands did have a system of patents awarded by both the estates general and the provincial estates from the late 1580s on, awarding a peak number of 119 patents in the 1620s. Yet in the eighteenth century, the number dwindled into insignificance (Davids, 2008, pp. 400-416).[5] Third, only a relatively small percentage of significant inventions were patented, as Moser (2005, 2021) has shown in detail. This was even true for the United States, where patenting was quite cheap relative to Britain.

There were many reasons for this low patenting rate besides the exorbitant cost. For some

[3]Johann Wolfgang von Goethe felt that the clever Englishman transforms an invention through the patent system's into a "real possession, and thereby avoids all annoying disputes concerning the honor due" and sighed that "one may well ask why are they in every respect in advance of us" (cited in Klemm, 1964, p. 173). Adam Smith (1762-66 [1978], pp. 83. 472) admitted that the patent system was the one monopoly (or "priviledge" as he called it) he could live with, because it left the decision on the merit of an invention to the market rather than to officials. Smith thought, somewhat unrealistically, that if an "invention was good and such as is profitable to mankind, [the inventor] will probably make a fortune by it."

[4]Charles Babbage, never one to mince words, denounced the patent law as a "system of vicious and fraudulent legislation" which deprived the inventor of the fruits of his genius and put the most productive citizens of society in a position of "legalized banditti." and "a fraudulent lottery which gives its blanks to genius and its prizes to knaves" (Babbage, 1830, pp. 333, 321).

[5]France, too had an institution that rewarded inventors, although it was entirely controlled by the state and one could dispute whether to call it a patent system (Hilaire-Pérez, 1991). Need to fill out.

inventions, secrecy and first-mover advantage were better ways to secure an flow of rents. Some were awarded prizes and pensions for having materially contributed to the welfare of the nation. For others the high costs in Britain was a serious obstacle. In a land of budding liberalism, the antipathy to monopolies often led to infringement suits being lost.[6] The bureaucratic complexity of filing for a patent was well-described in novels of the time, such as Dickens's satire of the "Great Circumlocution Office" in *Little Dorrit.* Others refused to patent as a matter of principle, because they felt that it would somehow deprive their fellow humans from the blessings of their invention, or were motivated by non-pecuniary incentives.[7]

The other seemingly unique institution that has been suggested as a possible factor in the Industrial Revolution is the English Poor Law. Beginning in the 16th century with the dismantlement of Church institutions, the English state gradually displaced the Church and voluntary associations as the main provider of poor relief. The "Old Poor Law" of 1601 formalized this system. It was modified repeatedly but remained in force in its basic outlines until 1834. In a seminal paper, Solar (1995) suggested a variety of ways in which the Poor Law contributed to British economic development and industrialization.[8] One ingenious mechanism was suggested by Greif and Sasson (2011), who argue that the Poor Law provided a safety net that encouraged people to take more risks and display more entrepreneurial behavior. Essentially, it provided a risk-sharing mechanism that

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[6]British judges (especially before 1830) were often hostile to patentees, considering them monopolists. One justice expressed a standard eighteenth-century view of patents by noting that "on the whole there was a great deal of oppression of the lower orders of men from Patents, by those who were more opulent" (cited by Robinson, 1972, p. 137).

[7]"When one loves science," wrote Claude Berthollet, the inventor of the critically important chlorine bleaching process to James Watt, "one has little need for fortune which would only risk one's happiness."

[8]Solar argues that poor relief functioned as health and/or employment insurance that was relatively free of moral hazard and adverse selection. Insurance made people more willing to work for wages in place of owner/tenant farming, which allowed a more efficient allocation of labor to the most productive farms. A large, stable pool of wage workers with no ties to a specific plot of land provided firms with flexibility in hiring and firing, further boosting the efficient allocation of labor.

led to more risk-taking. In a similar vein, Greif and Iyigun (2013) argue that the Old Poor Law helped foster social order and prevented riots. A somewhat different angle on the effect of the Poor Law is provided by Kelly and Ó Gráda (2014), who demonstrate that the Poor Law was associated with the disappearance of the Malthusian "positive check" in England. The significance of this development on long-term economic growth was substantial, as Malthusian negative feedback mechanism was one way in which the "iron law" kept wages and incomes low. By redistributing resources to the very poor, England's Poor Laws helped create a more secure and healthy working class.

Finally, a little-recognized institutional advantage of Britain was that it enjoyed a great deal of market integration. Many ancien régime continental states had barriers toward internal trade: in Germany and Italy, of course, political fragmentation paired to mercantilist regulations prevented free movement of goods and labor. But in France too, seemingly unified, internal tariffs hampered the free flow of goods, and were one of the early items that the French Revolution targeted for abolition (Dincecco, 2010). The French Revolution and subsequent upheavals (with its inevitable high costs) were necessary to eliminate an advantage that Britain had enjoyed since the Middle Ages. This institutional advantage was magnified by coastal shipping, and an improving highway and canal system. At first blush integration may seem to have benefitted Smithian rather than Schumpeterian growth, but regional specialization meant that the returns to investing in human capital in the regions that had a comparative advantage in high-skill production would increase (Kelly et al., 2021). Other connections from market integration and better transport to technological progress have been analyzed in detail in Szostak (1991). Here, too, institutions mattered: Britain was a highly taxed country, but by eschewing internal tariffs the British were able to benefit from growing regional

specialization and gains from (internal) trade.

Institutions and the roots of British Leadership

In a series of papers, Kelly, Mokyr and Ó Gráda (2014, 2020, 2021) as well as in other papers (Mokyr, 2008, 2021) we have argued that one underestimated driving cause of British leadership was, after all, a form of human capital, but one that was not much correlated with schooling and literacy. All the inventors and all the entrepreneurs of the world cannot bring about an Industrial Revolution (or any other form of creative destruction) unless there are skilled artisans and engineers who can read their blueprints, install and repair the equipment, provide the correct materials and fuels, and scale up their models. The abundant supply of such people in Britain was not self-evident, and indeed it needs to be explained. The evidence for this superiority seems unassailable. Contemporaries, both in Britain and on the Continent, loudly sang the praises of British artisans.[9] Moreover, for much of the eighteenth and nineteenth centuries, British technicians and mechanics swarmed all over the Continent, installing, operating, and maintaining advanced equipment in economies that wanted to compete with Britain, were able to get their hands on British equipment but could not find local engineers and other experts that could deal with the equipment (Henderson, 1954; Bensimon, 2011).

The success of the Industrial Revolution in the eighteenth century must be explained in part by the growth in artisanal skill in the preceding centuries. What mattered here was not just average

[9]Detailed evidence is presented elsewhere (e.g., Mokyr, 2009, pp. 107-108 and Kelly, Mokyr and Ó Gráda, 2020). One telling example is the widely cited statement by none else but Jean Baptiste Say, the inventor of Say's law and Adam Smith's most eminent follower in France. He noted in 1803 that "the enormous wealth of Britain is less owing to her own advances in scientific acquirements, high as she ranks in that department, as to the wonderful practical skills of her adventurers in the useful application of knowledge and the superiority of her workmen" (Say, [1803], 1821, Vol. 1, pp. 32–33).

skills, but above all the high-level capabilities and sophistication of the ones in the upper tail. Some examples of these great engineers on the eve of the Industrial Revolution are well-known, such as John T. Desaguliers (1683-1744), who combined scientific work with engineering.[10] Outside Britain, some famous and not so famous artisans illustrate the continuous progress of craftsmanship and mechanical competence, nowhere more that in clock- and instrument-making.[11] Scattered but consistent evidence indicates that between the invention of the printing press and the Industrial Revolution, European artisans were becoming more skilled.[12] If in 1500 Europeans still had to sail around Africa to acquire Indian textiles and Chinese pottery, by 1750 they were able to make their own. In most other areas, they had advanced far beyond anyone else.

To understand the roots of this critical development we have to realize that artisans were produced by other artisans through apprenticeship. Engineering schools were rare in this era, the first ones founded in France in the 1740s. But practically every artisan was trained through apprenticeship.[13] The contract between master and apprentice, was a complex transaction, because the master provided not only training but often also room and board. In exchange, apprentices paid

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[10]Desaguliers, the son of Huguenot refugees, was a tireless experimenter and practical instrument maker as well as one of Newton's most devoted acolytes. Among others he worked on the ventilation and heating issues, and redesigned chimneys and air heaters. He designed new types of water wheels and steam engines and constructed improved versions of various instruments, including a pyrometer, a barometer, a crane, and various pumps (Fara, 2004; Carpenter, 2011).

[11]The Renaissance produced some remarkable artisans in Western Europe, such as the Dutchman Cornelis Drebbel, the Cremona engineer (who worked in Spain) Janello Torriani, the French potter Bernard Palissy and the English clockmaker Thomas Tompion.

[12]Relying on scattered evidence, Epstein (2008, p. 71) has suggested considerable productivity growth due to the anonymous improvements and experimentation carried out by Europe's craftsmen, from the woolen industry to printing and clockmaking. Kelly and Ó Gráda (2017) show that in the seventeenth century, the English watch industry experienced a decline in the real price of watches by an average of 1.3 percent a year between 1685 and 1810, the result of an increasingly finer division of labor and learning by doing. Another example is the small arms industry. Hoffman (2015) showed the secular decline in the prices of firearms due to the growth in total factor productivity, estimating a rise in total factor productivity of pistols at 1.1 percent a year (1556-1706) relative to a low-tech product such as spades.

[13]Some of the following is discussed in much greater detail in De la Croix, Doepke and Mokyr (2018) and Mokyr (2019).

an upfront fee and promised to work for the master as a servant after completing the training. For obvious reasons, this very incomplete contract provided lots of possibilities for opportunistic behavior on both sides.

The solutions to this incomplete contract problem bring the focus back to institutions. In much of Europe, guilds still played a central role in enforcing and policing various aspects of apprenticeship. As guilds were becoming increasingly rigid and restrictive, this made it more difficult to train the nimble minds and dexterous fingers that Britain became famous for.[14] In Britain, enforcement was more or less independent of guilds. Instead, it was based on reputation mechanisms, that made many contracts self-enforcing as pointed out by Jane Humphries in a path-breaking paper (Humphries, 2003). Yet contracts were enforced in "the shadow of the law" and as a pis aller both sides had the option to go to court. Going to a formal court of law such as a Justice of the Peace was possible but given the cost and uncertainty of the outcome and the long duration of lawsuits, it was rarely resorted to even if some courts, such as the Lord Mayor's Court in London, employed speedier and less costly arbitration and more balanced reconciliation procedures (Wallis, 2012, p. 793). Above all, Britain in the eighteenth century can be described as a *civil economy* in which artisans and merchants depended on their reputations for business, a world in which most people were able to bring about a cooperative equilibrium that allowed markets to function reasonable smoothly — including the market for artisanal training. Opportunistic or other forms of bad behavior might taint someone as "not being a gentleman" and not being trustworthy, which

[14]Highly skilled artisans needed to be able to adapt to the needs of different if often related occupations (Cookson, 2018, pp. 106, 126). The most telling evidence for this agility was that a full one-third of the list of innovators compiled by Anton Howes made inventions that were quite different from the specialized training and skill of the inventor and invented in a range of seemingly unrelated fields (Howes, 2017, p. 36). High-level skills did not yet imply high levels of specialization. As Howes put it, "mechanical training could be applied to anything, from textile machinery to agricultural machinery to coachbuilding" (p. 24).

would be costly at many levels. Knowing this, the equilibrium path would be one of cooperation and part of that made the apprentice-master relation work better.[15]

In this regard, if we want to understand the institutions that fostered creative destruction, we should recognize not just the important of formal third-party contract enforcement but also the significance of "private-order" institutions, which were an integral part of the way society operated. Britain in the eighteenth century has been dubbed an "Associational Society" by its leading historian (Clark, 2000). Membership in clubs, societies, academies and various other spontaneous private-order organizations became a dominant feature of middle-class England. Many of these associations, of course, had little to do with the dissemination of useful knowledge. They were social gatherings, eating and (mostly) drinking clubs, sports and musical organizations, and so on. The significance of these associations was not so much on what they did, but in the creation of networks underlying the civil economy, in which economic agents met and exchanged information. These networks assured that most members would behave in an "honorable" manner and thus minimized the need for third party (that is, the state) enforcement of contracts.

The result was that Britain, thanks largely to its greater supply of high-skilled craftsmen, took the lead in the Industrial Revolution. Yet its leadership was almost entirely due to its superiority in *tacit* knowledge.[16] The nature of the Industrial Revolution and its aftermath was in slowly switching from tacit knowledge as the center of gravity to more formal knowledge, created by mathematicians, physicists, chemists, medical doctors, and people schooled in "engineering science."

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[15]Humphries (2010, pp. 282-284) recounts a number of cases in which disputes between master and apprentice were resolved by social and reputational pressures, many of them supported by the need of the master to maintain his social relations with the parents.

[16]In 1752, the French Academician and industrial consultant Mignot de Montigny wrote that "The arts never pass in written form from one nation to another, only the eyes and practice can train men in this work" (cited by Harris, 1998, p. 550).

In other words, while Britain seems to have enjoyed a comparative advantage in tacit knowledge and the "knacks" of the trade, the European Continent had a comparative advantage in formal and codified knowledge. The most extensive technical book on coal and collieries was written by a French physician, Jean-François C. Morand (1768-79). While England had the most developed and sophisticated copper-smelting industry in eighteenth century Europe, economic historians depend on Continental sources for its description (Harris, 1974, p. 97). Perhaps the largest compilation of technical descriptions of manufacturing and related activities was contained in the enormous (80 vols) collection of industrial handbooks published by the French Académie before the revolution, namely the *massive Description des Arts et Métiers* published between 1761 and 1788, including 13,000 pages and 1804 plates.[17] The great encyclopedia of d'Alembert and Diderot, too, contained a ~~great deal of~~ technical descriptions. Even in civil engineering, where British superiority was among the most pronounced, French texts dominated.[18] The English produced and engineered; the French wrote about it. The historical dynamic, however, worked against the British as technology began to rely more and more on formal science.

Destructive Creation. The unprecedented progress that Enlightenment *philosophes* had hoped for exacted a high price. The Industrial Revolution was responsible for the unprecedented growth of the new industrial towns, of which Manchester and Glasgow were the best examples. Even

[17]The chief editor was Henri-Louis Duhamel du Monceau, a distinguished botanist and naval architect one of the most remarkable figures of the French Enlightenment, who personified the practical side of Enlightenment science. "His hallmark was neither style nor wit. It was usefulness." (Gillispie, 1980, p. 338).

[18]Among the notable engineering texts were "the best contemporary account of the steam engine" written by Gaspard de Prony (1794), the widely-read and translated *Essay sur la Composition des Machines* published in 1808 by Agustín de Betancourt and José Maria Lanz, and J.P.N. Hachette's *Traité Elémentaire des Machines* (1811). See Cardwell (1994, p. 205).

non-Marxist historians have agreed that the creation of an industrial and urban wage-labor class, whether one uses the term "proletariat" or not, was a decisive factor directing the evolution of Victorian society. The emergence of an urban working class in congested, unhealthy, and disagreeable industrial towns was described with alarming detail by contemporaries. Of those, Friedrich Engels's famous book *The Condition of the Working Class in England in 1844* has received the most fame or notoriety, but his descriptions are consistent with (and to some extent derived from) those of other contemporary observers of life in the new industrial towns, such as Peter Gaskell, William Alison, and James Kay-Shuttleworth. No document laid this fact out more clearly than Edwin Chadwick's justly celebrated *Report on the Sanitary Condition*, first published in 1842. In it, the environmental impact of the Industrial Revolution in urban areas was described in great detail.[19]

Modern research has put formidable quantitative muscle in this anecdotal skeleton. Huck (1995) showed in detail the appalling levels of infant mortality in British industrial towns and sees them as evidence of stagnant living standards in these cities, in which a worse physical environment offset higher wages. In two remarkable papers, Walker Hanlon (with Brian Beach) have shown how the heavy use of coal, touted by many as the most striking feature of the Industrial Revolution, led to major environmental effects on the life of the people living in the new industrial cities, as measured through its effects on life expectancy.[20] Moreover, he shows that the use of coal slowed

[19]Chadwick was no socialist, but he described what he saw: "The familiarity with the sickness and death constantly present in the crowded and unwholesome districts, appears to re-act as another concurrent cause in aggravation of the wretchedness and vice in which they are plunged. Seeing the apparent uncertainty of the morrow, the inhabitants really take no heed of it, and abandon themselves with the recklessness and avidity of common soldiers in a war to whatever gross enjoyment comes within their reach" ([1843], 1965, p. 198).

[20]Beach and Hanlon (2018) estimate that raising local industrial coal use by 1 SD from the mean increased infant mortality by roughly 6–8% and under-5 mortality by 8–15%. In terms of life expectancy, given mortality patterns in the 1851–60 decade, the impact of a 1 SD increase in local industrial coal use on under-5 mortality is associated with a reduction in life expectancy at birth

down city growth and that had there been more regulation, growth would have been faster (Beach and Hanlon, 2018; Hanlon, 2020). The Industrial Revolution took place in an institutional environment that had changed dramatically from a mercantilist world of regulation and control to a liberal world that was as close to a laissez faire as any economy is likely to get. Yet the ~~patent~~ market failures that were obvious in the new industrial urban centers pointed to the inevitable demise of the relatively purist laissez faire policies of the first half of the nineteenth century.

Another striking example of industrial pollution is the Leblanc soda-making process, a French invention (1785) but as in many other cases first deployed on an industrial scale in Britain, in this case primarily by an Irish-born entrepreneur named James Muspratt at St Helens in Lancashire. The invention was a major technological breakthrough, as soda was an important material in a host of chemical industries. As Reed (2013) points out, the waste product of the Leblanc process referred to as *galligu* --- "a wonderfully onomatopoeic word to describe a black, evil-smelling, viscous material." A ton of soda implied about 1.75 tons of galligu. Galligu was not just malodorous, it was also quite toxic, containing arsenic and other heavy metals, leaching in the ground water. Most was deposited on waste land adjoining the works, scarring the landscape and polluting the surrounding land, air and water, some of which is unusable till the present day. By the 1870s the annual amount of this waste produced in Britain is estimated at close to 500,000 tons. People living close to the works complained vociferously about the "nuisance" created by this pollution. In addition, releasing hydrogen chloride from tall chimneys without any amelioration proved a constant scourge for landowners and people living close by the works who were affected

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of 0.84–1.58 years or 2.19–4.11%. In the most heavily polluted cities, such as Sheffield, Manchester, or Birmingham, where coal use was more than two standard deviations above the national mean, the effects were quite large, which could explain Huck's (1995) findings.

by the debilitating effects of the gas, as well as for manufacturers fighting the legal redress for the alleged damage inflicted. Soda-making was the driver behind the first environmental legislation, the Alkali Acts of 1863 and 1868.

The Industrial Revolution's ~~destruction was~~, perhaps inevitably, most devastating to specific human capital. The mechanization of skilled tasks destroyed the value of workers' skills and abilities, and they famously led to considerable resentment that drove many machine-breaking riots. The Luddite riots in the Midlands between 1812 and 1816 are widely cited, but they were only the tip on the iceberg. Much of the displacement took place in the wool industry, which for centuries had been the mainstay of the British textile industry and besides technological change was suffering from increasing competition from cotton textiles, which were growing at a much faster rate. Scribbling mills (which prepared the raw fleece for carding) and gig mills (which brought up the nap on woolen fabrics) threatened traditional skills. Here creation was truly destructive: Benjamin Gott, a Leeds wool manufacturer, built a new factory in Leeds named Bean Ing, which was a paragon of modern technology and rational management.[21] But this new age of large mills threatened to become the workers' worst nightmare, wiping out their livelihood and way of life. In the "West Country" of England (Gloucestershire, Wiltshire, Somerset) the highly specialized wool industry, mostly consisting of small independent producers, could not survive mechanization (Randall, 1991, pp. 40, 45). De-industrialization ensued, but not before some serious rioting occurred.

Historians have been more sensitive to the non-pecuniary costs of the Industrial Revolution than economists, who have tended to dismiss the resistance as a form of rent-seeking. In an eloquent

[21]A classic text on the Leeds wool industry is an eloquent description of what creative destruction can look like: "The boldness of Gott's conception of a factory in 1792 is perhaps without parallel... Bean Ing sprang out of nothing; it was an ideal, a dream of the new age of industrialization, materialized forthwith in bricks and iron, in steam and machinery." Crump (1931) p. 255.

passage, Randall (1991, p. 48) points to what he calls the "amorality of the factory system." The old system, customs protected the worker's rights and dignity — the factory steamrollered customs, replacing a "moral economy" with the amoral (though not immoral) economy of pure, impersonal relations. For the economist, a more prosaic way of defining the issue is to point out that the factory reduced the choice set between leisure and income to a single point, whereas in a world of self-employed cottage industry workers, they could optimize over a continuous choice set. Yet this captures only one aspect of the costs of creative destruction.

The most famous example of destructive creation during the Industrial Revolution was the fate of the handloom weaver (Bythell, 1969). Handloom weavers have often served as an example of the costs of laissez faire economy subject to exogenous shocks.[22] Hobsbawm tersely suggests that they "starved progressively in a vain attempt to compete with the new machines" (Hobsbawm, 1969, p. 93). The mechanization of weaving, first in cotton and then in other textiles, clearly threatened and eventually eliminated this occupation, one of the largest single ones in Britain.[23] The story is far less clear-cut than the pessimist accounts of Thompson and Hobsbawm indicate, yet at the end of the day there is no question that even in the most optimistic accounts, they have been dubbed "the leading example of technological unemployment during English industrialization" (Hartwell, 1969, p. xi). Lyons (1989) has argued that while the plight was real enough, it was a matter of one generation that could not readily adapt, but that the offspring of the weavers found employment in

[22]In the words of the most influential social historian of the Industrial Revolution of his generation, "In the weavers's history we have a paradigm case of the operation of a repressive and exploitative system upon a section of workers without trade union defences. Government not only intervened actively against their political organizations ... it also inflicted upon the weavers the negative dogma of the freedom of capital as intransingently as it was to do upon the victims of the Irish Famine" (Thompson, 1963, p. 312).

[23]As late as 1834, the Select Committee appointed to look into the weavers' plight estimated that 800,000 or more people were wholly dependent on the loom (Great Britain, 1834/35, p, 3). Bythell (1969), p. 57 estimates the number of weavers only in cotton at 200,000-250,000.

a rapidly growing economy. Moreover, the ranks of weavers had swollen considerably in the "golden age" decades when spinning had been mechanized but power looms were still few and imperfect. Free entry into the industry meant that during periods of boom, the growth in the numbers of weavers kept wages in check, but that when conditions turned down as powerlooms became more common after 1820, many were driven to exit the industry. However, as Bythell (1969, pp. 58-61) notes, the picture is muddled by the fact that for many handloom weavers, the work was part time, even casual employment. Moreover, the transition occurred in his view with remarkable speed and ease, and what was notable was the speed with which they disappeared, rather than the "protraction of their agony" (Bythell, 1969, p. 268). The conclusions are, of course, debatable (Perkin, 1971). The abruptness that Bythell underlines meant that a whole generation did not have the time needed to adapt; technological unemployment was less of a threat when the decline in the demand for labor in the affected industry was slow and gradual.

Another sector of the economy that was disrupted by destructive creation were framework-knitters. Known as "stockingers", they were located in the east Midlands, half of them in Nottinghamshire. Certainly by the 1830s they had fallen on very hard times and had to make their children join the work in a desperate attempts to survive.[24] The decline of this trade and the "make-shift economy" were factors in the riots in Nottinghamshire in the 1810s which had been thought to be moderate compared to the Luddite riots in Lancashire and the West Riding of Yorkshire (Roberts,

[24]In a special section dealing with the hosiery trade, the *Royal Commission on Children in Factories* of 1833 commission (Great Britain, 1833) reported that "the long and extreme depreciation in the value of the stocking maker's labour ... [had caused] "hopeless poverty producing fearful demoralization (p. 579). A local witness before the same Commission describing the state of framework knitters maintained that " the condition of these persons [children between the ages of six and eighteen] is very low and depressed ...the general appearance both of men and women and children employed in this branch of manufactures, their habits of work and subsistence are more destructive of health, comfort, cleanliness and general state of well-being than any [other] state of employment." Another added that "They are, many of them, unhealthy and dyspeptic; ….I can tell a stockinger well by his appearance; there is a paleness and certain degree of emaciation and thinness about them.. hopeless poverty is producing fearful demoralisation" (pp. 535, 557).

2017). The transformation of the British economy, amplified by the shocks of the Napoleonic Wars, caused a contraction of what social historians have called the "makeshift economy," the "patchy, desperate and sometimes failing strategies of the poor to make ends meet" (King and Tomkins, 2003). It may well be that the precariousness of the economic status of framework knitters in the midlands pushed them into rioting. What is obvious is that the British authorities had little sympathy for these victims of destructive creation. In Hobsbawm's eloquent words, industrialization first increased the numbers of handloom weavers and framework-knitters until the end of the Wars. "Thereafter it destroyed them by slow strangulation... skilled craftsmen were degraded in to sweated outworkers ... pre-industrial traditions could not could not keep their head above the inevitably rising level of industrial society" (Hobsbawm, 1969, pp. 90-91).

A very different but striking example of the destructiveness of the Industrial Revolution is provided by a social historian, Emma Griffin (2018). One of the costs of the Industrial Revolution, she believes, is the disruption of the allocation of resources *within* the family, at the micro-micro level. Industrialization raised male incomes, "but at the same time it changed patterns of behaviour that had historically helped to ensure that children received the food they needed." High wages, she feels, "went hand in hand with the erosion of age-old social pressures upon men to provide for their families, resulting in the divergence between male wages and family living standards" (Griffin, 2018, pp. 102-103). While Huck and Hanlon document the cost to the urban working class in terms of disease and pollution, Griffin stresses the grinding misery of the rural poor. Searching close to 350 autobiographies for references to hunger and similar terms, she finds that in rural households, dependents were most likely to suffer from occasional hunger. Yet in industrial regions, too, childhood deprivation was common. Griffin's argument is that the Industrial Revolution was both

an economic and a cultural event. “Wages formed the bedrock of well-being within families, but a complex series of social and cultural norms were needed in order to turn those wages into well-being.” Men whose real wages were increasing had a greater propensity “of reneging on their responsibility to provide with the consequence that children’s living standards lagged behind the male wage” (Griffin, 2018, p. 106). Strikingly, infant mortality — a standard metric of living standards — stayed stubbornly high in England until the closing years of the nineteenth century.

Conclusions

How dangerous is destructive creation? It is no accident that economic historians speak of “technological progress” but “institutional change.” Technology, like all forms of knowledge, is on the whole cumulative: we know (most of) what previous generations knew, but we know more. Especially since the invention of the printing press and other ways of reproducing knowledge, it is rare for knowledge to be lost or forgotten. Institutions, on the other hand, tend to follow no monotonic time path. While there have been periods of noticeable improvements toward inclusive and open societies in which human rights and individual freedoms were respected, more often than not they were followed by periods in which autocratic and repressive regimes took over. The corridors to open and inclusive societies are narrow and full of dead-ends (Acemoglu and Robinson, 2018). Technology and institutions, however, affect one another in subtle ways.

The Industrial Revolution provides an example of how technological progress and institutions interacted. As we saw, the institutional environment affected the rate of technological progress. But the reverse effect was there as well. The rise of the factory and polluted and congested industrial urban centers made liberalism in its purer forms unsustainable. Child labor laws, the regulation of

urban amenities, and concern about public health and consumer safety all came to the fore during the Industrial Revolution. Urban poverty may not have been all that much worse than rural poverty, but it was more visible and salient. Regulation and growing state control followed, and in the end the twentieth century produced the welfare state, often through "a winding road" — as one might expect from a highly non-linear historical dynamic of co-evolution (Boyer, 2019).

Perhaps one of the dimensions that economic historians of technology have left out from their discussion is that technology is about more than just the control of natural forces by humans; it is also determines the tools by which humans influence, control, and manipulate one another. Any regime relies on instruments to exercise power and help create obedience: Josef Goebbels's radio and Xi Jinping's surveillance cams and facial recognition algorithms are just two examples of how autocratic regimes harness the cutting edge technology of their age to suppress human rights and liberty. Perhaps, then, that threatens to become the worst enemy of progress, and the ultimate form of destructive creation. Will the inventiveness and ingenuity that has made humanity so much richer than any generation in the past also create the capabilities by which malevolent rulers will control their citizens through lies and terror?

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