Introduction

The Industrial Revolution was about more than inventions. Instead of individual machines conceived by heroic inventors in a flash of discovery, this is a book about systems and networks, and the worlds that got the machines running, and the way the world changed to make the devices work. Making machinery operational required resources only available outside the machines themselves, even as getting the machines running meant rearrangements of labor and power and raw material supplies, of markets and distribution and finance, and of consumer tastes and global geopolitics. The famous machines used inputs to operate. They also needed markets for the things they made, and marketing too. Without demand, without buyers for their products, mechanization would have failed because investing capital in machines would not have made profits. Without supplies and without workers, likewise, the storied inventions of the Industrial Revolution would have stopped. The chimneys and mills, the wheels and water and feudal arrangements for their use, slave plantations and guild prerogatives, transportation and communication networks, government protection and imperial competition, all played a role in making specific devices work. The relationship between changing machines and their changing contexts is the subject this book investigates.

The classic case of Industrial Revolution refers to transformations in the textile business of northern Britain in the late eighteenth century. These changes included using machines, powered by inanimate energy sources, to make cloth in factories, resulting in mass production of fabric that sold around the globe. These shifts were a response: the reaction of regional cloth merchants to their fears about cotton fabrics imported from India. These clothiers operated a dynamic, powerful, intricately articulated textile industry that had taken shape in medieval England before expanding in the 1500s and 1600s with the new commercial links between Europe and the trade of the Indian Ocean. In the eighteenth century, merchants who responded to these changes by investing capital in factories and machinery became industrial capitalists – a new kind of businessman. They did not act alone, though. Britain's tradesmen

became industrial manufacturers with the help of the state. It was not laissez-faire capitalism that made industrialization possible: the mercantilist ideology of the age ensured government support for both international adventures and home industry. Instead, a protected domestic market and competition for consumers elsewhere – in Africa and America, especially – provided the economic context for the piecemeal adoption and combination of practices and devices that worked, over time, as the new emerging technologies of the day. Social structures and existing institutions, from market rights to the established Church of England, influenced when and how machinery worked in everyday but changing systems of production.

Justification

The Industrial Revolution as a coherent episode of technological change is a bit of a conceit, constructed by later minds out of a wide array of incidents that seemed fairly random at the time. The usual events evoked by the phrase "Industrial Revolution" took place in a few counties in the British North, between the 1760s and the 1840s, where the local cloth merchants of a national textile industry were changing how they did business. Within shifting frameworks of government protection and global competition, they invested in machinery to ensure regular supplies of goods to sell. They contributed to reorganizing global trade patterns, individual household structures, and consumer fashion as part of that process.

The revolutionary nature of their activities can be established by certain data, which indicate what this book attempts to explain: how did cotton manufacturing increase so dramatically in the north of England in the 1760s to 1840s? What role did machinery play? Where did the devices come from, and how were they made to work? What changed, and what stayed the same, in British cloth production in those eight decades? Answering these questions means seeing machinery as the heart of the story and attempting to understand its origins as well as its impact. Placing machinery in a middle position, as both cause and effect, provides frameworks to explain the rise of mass production, one result of industrialization. Mass consumption and waged labor were additional results of industrialization, as was a specific imperialist organization of the globe. The data on cotton consumption, on the value of output of the cotton industry, and on the importance of cotton to the larger British economy, therefore voice the questions that this book attempts to answer.

Manufacturing means turning unrefined commodities into consumer goods, so the consumption of commodified raw material is one thing this book wishes to explain. Raw cotton imports to Britain increased

a hundredfold during the Industrial Revolution, from 4.2 million pounds in 1772 to 41.8 million in 1800 and 452 million in 1841. In terms of the output: in 1766, Britain exported cotton goods worth a total of £221,000; in 1800 the figure was £5.4 million (two-fifths of the nation's total export of manufactured goods). By 1840, the figure was £22 million. (This would be another hundredfold increase if currency measures were not often distorted by inflation). Cotton was 1 percent of British industry in 1770, rising to 10 percent of the whole manufacturing sector of the British Isles in 1841.[1] In comparison, the tech sector was 0.8 percent of US Gross Domestic Product in 1980 and climbed to 5.2 percent by 2015.[2] The cotton industry of Britain rose higher, though not as fast. By the end of our story, cotton manufacturing was a more important part of the British economy than the tech industry is for the United States today.

These data indicate a shift in human experience. The rapid increase in the inputs and outputs of cotton, in a few counties in the north of Britain, about 150 years ago, accompanied a fundamental change in how people live. It was in this period that most people changed from making what they used to buying those things that other people made. Very few of us today spin our own yarn, weave our own cloth, or sew our own clothing. Most of what we wear was made by other people, far away, on machines owned by yet others; in other words, was made industrially. The end of this story, the mass production of textiles for distant consumers, had its beginnings in a very different set of goals. Men who bought machinery to multiply and improve on traditional work sought to imitate luxurious imported fabrics. They also pursued and achieved government protection for their industry, and they sold their goods into colonies and around the world. During the Industrial Revolution, technological systems around the adoption of new machinery shifted from product innovation (making new goods) to cost competition (making goods more cheaply), from luxury and niche production to mass market and mass production. The individual person's experience of making and using goods is different, as a result, than it was before industrialization.

[1] Joseph Inikori, *Africans and the Industrial Revolution in England: A Study in International Trade and Economic Development* (Cambridge and New York: Cambridge University Press, 2002), 78–79; David S. Landes, *Unbound Prometheus: Technological Change and Industrial Development in Western Europe from 1750 to the Present* (Cambridge: Cambridge University Press, 1969), 41–42; Edward Baines, Jr., *History of the Cotton Manufacture in Great Britain* (London: H. Fisher, R. Fisher, and P. Jackson, 1835), 215; Christine MacLeod, *Heroes of Invention: Technology, Liberalism, and British Identity, 1750–1914* (Cambridge and New York: Cambridge University Press, 2007), 64; "Commercial Statistics: Annual Export of British Manufactures," *Hunt's Merchant's Magazine* 5 (July 1841), 385.

[2] Prasannan Parthasarathi, *Why Europe Grew Rich and Asia Did Not: Global Economic Divergence, 1600–1850* (Cambridge and New York: Cambridge University Press, 2011), 12; Ian Hathaway, "How Big is the Tech Sector?," blogpost, May 31, 2017.

Definitions

A three-part definition of industrialization guides the analysis in this book:

1. The mechanization of some task or series of tasks previously done by hand. New machinery is often taken as the cause of technological change. Here it is examined as a physical expression of the changing world around it. Both the development and adoption of machinery are part of a bigger story about how methods changed, and who did the work, and where the raw materials came from and where the finished goods went.
2. The separation of production from consumption – the people who use goods are not the ones who made them. This often includes the removal of work from home, and of labor from leisure. It also intimates a division of labor, in which the tasks of making something are performed by different people, instead of by one person who makes a piece from beginning to end.
3. The development of regular flow and standard characteristics of physical objects, from raw materials to finished products, from supply to demand. This incorporates the predictable procurement of expected materials, and established links to distribute the finished goods. One example is the cotton trade between North America and Britain that fed raw materials into machines in factories as these developed. The Industrial Revolution both relied upon and stimulated this regular flow of materials. Another example is consistency of goods mass-produced, rather than made individually.

This three-part definition draws on a similar description, given in the first pages of David Landes' 1969 book *Unbound Prometheus*, which defined industrialization primarily in terms of the replacement of muscle with inanimate power. This emphasis on generalized inanimate power neglects important differences in the technological systems around each type – wind, water, steam – as well as the role of horses (muscle power) in early industries. Treating inanimate power as one single thing therefore omits the contingencies that made one system more attractive than another in specific times and places. So instead "mechanization" here replaces that part of the definition, and the energy source that powered a machine will be treated as part of its production system. The second part of the definition draws on recent scholarly recognition that changes in consumption accompany or even lead to changes in production – that demand helps explain changes in supply. Finally, the third part of this definition expands on Landes's "marked improvement in the getting and working of raw materials, especially in what are now known as the metallurgical and chemical industries." By keeping the focus of this book on

one single sector, here the transformations in raw material supplies include the use and technological expansion of the plantation system of production to the cultivation of cotton in the American slave south.[3]

Existential Questions

Did the Industrial Revolution really happen? Scholars ask: Was it a revolution – a dramatic change in a short period of time? Was it industrial, or did another sector (agriculture, for example) experience greater efficiency gains? Those who dispute the idea of an Industrial Revolution have good evidence on their side. They point out the component mechanization, stretching back into medieval wool finishing and silk throwing, that this book sketches in Chapter 1. Much of the machinery so often used to explain technological change was already available, and some was even adopted, in the long centuries before the few decades we call the Industrial Revolution. Quantitatively, too, the late eighteenth-century "spurt" of manufacturing output "was confined largely to cotton goods" and "it was not until the 1820s that the quantitative weight of new industries imposed itself on the economy as a whole." Change was gradual, investment small relative to the entire economy, and only a small percentage of even the English population experienced the dislocations and opportunities of the age.[4]

Contemporaries, of course, did not use the term "Industrial Revolution," although its later participants and observers knew they had lived through something remarkable. They described it in the same terms used here, as a cotton manufacturing industry that developed in the north of Britain in the last decades of the eighteenth century, culminating in the period in which they were living – the 1830s and 1840s. These men include William Radcliffe and Robert Hyde Greg, Karl Marx and Edward Baines, all of whom we shall meet in Chapter 5, as our story comes to an end. By then, the events described here had begun to take shape as an historical incident with clear lessons to impart – a mythical history, devised to support a particular ideology and political goal – about innovation, and genius, and the role of technology in causing social change. Local industrialists celebrated their own acumen and won their political voice.

[3] David Landes, *Unbound Prometheus,* 1; Inikori, *Africans and the Industrial Revolution,* 156–65.
[4] P. J. Cain and A. G. Hopkins, *British Imperialism: 1688–2015* (Abingdon and New York: Routledge, 2016), 82.

Two generations later, in 1884, Arnold Toynbee generally receives credit for first naming the Industrial Revolution.[5]

By the time the Industrial Revolution received its name, the mythical version of events had already taken hold, commemorated in monuments and celebrations of heroic inventors, to whom were assigned the individual creation of ingenious machines that changed the world. Historians would spend the next hundred years trying to correct the schoolboy simplification that saw only a "wave of gadgets" that had "swept over Britain" to create that nation's nineteenth-century economic growth and imperial power.[6] Biographies of engineers circulated, as they do today, celebrating the heroic inventors of the tech industry. Victorian communities even erected statues to their favorites, to whom they credited their wealth. The phrase "Industrial Revolution," coined in 1884, simply expressed an invention myth, abridged from real events, that already resonated.

Technology in the Industrial Revolution intends to have it both ways. It treats the Industrial Revolution as real and revolutionary, but emerging from and encompassing long-term gradual shifts. It may seem contradictory to both accept the revolutionary nature of the period between the 1760s and 1840s and at the same time recognize its precursors and aftershocks, reverberating in long cycles around those decades, but such experiences abound in the history of technological change. Causation is complicated around machinery. Industrialization happened gradually, bit by bit, and then appeared suddenly, in the nineteenth century, and grew from there. One important reason industrialization happened successfully was the application of large-scale plantation agriculture to the cultivation of cotton fiber in the New World – but this happened during the Industrial Revolution, and accelerated as a result. Another cause of industrialization was the threat posed to an important national industry by the cotton textiles imported from India, and one effect was the colonization and imperial exploitation of British India. In these histories, mechanization stands between cause and effect, and partakes of both. The machinery at the heart of the story was only one part of a changing system and did not shift all the rest on its own. The belief that inventions caused industrialization was itself invented by industrialists who celebrated themselves and their industry in the nineteenth century. In that history, the reasons those machines worked then and there remains unexplained.

[5] Baines, *History of the Cotton Manufacture*; Karl Marx, *Das Kapital* (Hamburg: Verlag von Otto Meissner, 1867–1894); Arnold Toynbee, *Lectures on the Industrial Revolution in England: Popular Addresses, Notes, and Other Fragments* (London: Rivingtons, 1884).
[6] T. S. Ashton, *The Industrial Revolution, 1760–1830* (Oxford University Press, 1968), 48.

Debates and Terminology

In utilizing a longer timeline and larger framework, *Technology in the Industrial Revolution* sometimes employs contested terminology without criticizing the language, taking a side in the debates, or rationalizing the use of the term. For example, proto-industrialization is a troublesome word: it indicates an outcome (industrialization) and identifies steps that seem to lead there. It therefore implies that the outcome was pre-ordained, rather than contingent and uncertain at the start. This book uses the term "proto-industrialization" but tries to avoid assuming which ending is on the way. Instead it describes events emerging from local history and participating in global processes. Likewise, "industrialization" itself is defined by economists as the movement of resources from agriculture or extraction into making things "without much direct input of natural resources" – fabrication, in other words, rather than processing.[7] This book is interested in how that version of "making things" first originated. Examining the reasons behind the success or failure of particular production systems means seeing the way they fit into the world around them, even as that world was changing. Rather than assuming one technical system was better than another, the goal is to identify which elements in each system served what purposes.[8]

Guilds receive similar treatment: their interest for students of industrialization lies not in whether they were good or bad, beneficial or economically inefficient – points that professional historians debate. Instead, this book traces some of the steps by which guilds were transformed into new collective institutions, for capital and for labor, during industrialization. The reasons when and where and why the guilds declined matters less here than the permutation of some parts of guild structures into trade unions and business corporations. Likewise, this book attempts to explore a major transition point in the history of capitalism – from merchant to industrial capitalism – without arguing that one superseded the other, nor that mercantilism disappeared as industrialism emerged. This book defines "capitalism" as the investment of capital, put into operation in the hope of generating a return – capital risked on the assumption that wealth can be grown. While economists define capitalism as an economic system in which private entities own most property and make economic decisions free of centralized planning and government control, this book watches that ideal first emerge. And so it approaches

[7] John C. Black, *Dictionary of Economics*, 2nd ed. (Oxford and New York: Oxford University Press, 2002), s.vv. "industrialization" and "industrial sector."
[8] Regina Grafe, "Review of Epstein and Prak, *Guilds, Innovation, and the European Economy*", in *Journal of Interdisciplinary History* 40, no. 1 (Summer 2009): 78–82.

capitalism from the past that predates it, when public and private were harder to distinguish. The key is the investment placed at risk in order to grow.

Methods and Approaches: The Historiography of Technology

Wide historical research into the events known as "the Industrial Revolution" has created specialization. Each historical subfield has its own interests and questions. *Technology in the Industrial Revolution* both draws upon and speaks primarily to economic history and global history, and utilizes the work of labor and social historians and environmental historians as well. However, its guiding approaches and methods have been developed in the history of technology. Technology's historians use two basic approaches to understand how technology works: internalist and contextualist. Internalist investigation studies devices and methods without much reference to the world outside the technologies. Contextualist analysis does the opposite and incorporates the outside context – costs and prices; laws and institutions; cultural expectations about work, spending, and investment; and social norms around gender and age – into understanding the machinery. Internalist analysis tends toward technological determinism: machines appear and cause change, and each is better than the last. Contextualism slides toward social construction, in which the success of the technology is caused by events outside the machine. Over the past thirty years, historians of technology have moved toward reconciling the two approaches, in order to use the workings of machinery to understand both its causes and its effects.[9]

Combining contextual analysis with internalist understandings, Thomas P. Hughes's foundational *Networks of Power: Electrification in Western Society* fashioned what historians of technology call "systems theory" in explaining the development of large-scale technological systems like those that supply electricity in the western world. Rather than identify an inventor of the light bulb, he investigated the history of electrification in four different cities in Europe and the United States, and explained how the different sources of power supply, and the geography of customer bases, resulted in distinct technological systems for electrifying New York, Chicago, London, and Berlin. Hughes pointed out that machines develop and operate within systems, and politics and

[9] John M. Staudenmaier, S. J., *Technology's Storytellers: Reweaving the Human Fabric* (Cambridge, MA: MIT Press and the Society for the History of Technology, 1985), introduction and chapter 1.

economics play a role in how those took shape. In each city, the constellation of generators, transformers, transmitters, wires, outlets, and even light bulbs, in homes, businesses, and transport systems, had different designs. Over time, it became more and more difficult to change any particular part of the system. The parts fit together, and substantial changes to one segment would mean changing the rest – an increasingly unlikely undertaking, as the system matured and grew more complex. That is how, in Hughes's systems theory, the social construction of technological systems turns eventually into determinism as the system ages. Electricity – a system deeply influenced by politics, economics, and society – became harder to change as it influenced and shaped the world around it. Hughes' systems theory is perhaps most famous for its articulation of the "reverse salient," (borrowed from military history) in which bottlenecks to the development of a working system draw the attention of engineers and other systems-builders, so that the technology develops as a unified whole.[10]

In his later work, Hughes developed the concept of "stakeholders" in systems, including all the relevant social groups that influence a technological system. For example, building a bridge in a city can involve not just engineers but also politicians and planners, zoning boards and local businesses, and residents enrolled in advisory or protest groups. Construction contractors and materials suppliers also play a role in the design decisions. All these people and institutions and objects participate in how the system eventually is designed and built, and a successful engineer or project manager will have to manage all the stakeholders in order to advance the project. Such actors can be called heterogeneous engineers because their problem-solving uses more materials than those found in the physical world. This concept of stakeholders enlarges the analysis of a technological system beyond physical artifacts and the abstract power of politics, economics, and society. It includes human choices and organizations in the story of how technological systems took shape the way they did. The heterogeneous engineer is a useful concept for understanding the work performed by the renowned inventors of industrialization, whom we shall meet in Chapter 2.[11]

In expanding technical systems to include a wide range of actors and objects, the networks of their interactions, their economic

[10] Thomas P. Hughes, *Networks of Power: Electrification in Western Society, 1880–1930* (Baltimore and London: Johns Hopkins University Press, 1983).

[11] Wiebe E. Bijker, Thomas P. Hughes, and Trevor Pinch, eds., *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology* (Cambridge, MA: MIT Press, 1987; rev. ed. 2012).

interests, and the groups they participate in creating and maintaining, this book employs a rudimentary version of actor-network theory (ANT). Developed by Bruno Latour and other sociologists who work in the history of technology, ANT provides a way to connect people's actions and human agency to the forces that seem to operate outside mortal control. It replaces the concept of society, which sounds too settled, with the notion of "the social," which seems more contingent and ongoing than "society." In ANT, the social is an assemblage of people, institutions, and artifacts that are continuously reorganizing in ways that form the social realm. The theory avoids abstractions ("capitalism" or "patriarchy") and instead examines the practical steps people take, the institutions they create or join, and the artifacts they employ and develop, in their constant process of assembling their worlds. While historians of capitalism emphasize the forces that shifted human behavior from subsistence into market orientations, historians of technology avoid abstract causes, arguing that these forces only act through specific deeds. Rather than employing "capitalism" as a word that explains human behaviour, modern history-of-technology methods – and ANT in particular – instead trace the way that people and their actions embody capitalist activities.[12]

Another way historians study technology is to explore how it is used, rather than focusing on innovations. Museum professionals, for example, are shifting away from simple displays of machinery to find ways to explore and exhibit people's experiences of technologies. These approaches include considerations of the maintenance that keeps systems working. Daily use and the maintenance of existing devices are primary experiences that people have with technology. David Edgerton has criticized his fellow historians of technology for focusing too much on innovations, on "the early history of selected technologies which later came into widespread use." *Technology in the Industrial Revolution* pleads guilty to this charge. It also stems from an equally old-fashioned history-of-technology approach that some might call myth busting – undermining invention myths by identifying their contextual causes, adding complexity and nuance to the story of how technology was made to work. In other words, this book pursues what Edgerton describes as technology in history – a marriage of devices with their contexts. It argues that novelty draws upon elements that already exist, even as those change to get new things going. Today's

[12] Bruno Latour, *Reassembling the Social: An Introduction to Actor-Network Theory* (Oxford: Oxford University Press, 2005).