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Introduction

Knowledge and industrial development: the stakes

By "the first knowledge economy" we refer to the era of the Industrial Revolution from roughly the 1760s to the 1850s, first in Britain and then in selected parts of Northern and Western Europe, with particular attention to Belgium. Only and first in this period did economic growth based upon technological innovation become continuous. There were ebbs and flows to be sure, recessions, even depressions, but still the wealth of the affected nations continued to grow, and, slowly, so too did per capita income of families. Put another way, the so-called Malthusian dictum, that prosperity would fuel population growth that would inevitably be stopped by food shortages, came undone. By the last quarter of the nineteenth century, real wages had risen, as had the population in general, and output in agriculture and manufacturing had also risen to meet the new demand.

Since that time the debate has raged as to how the dictum had been broken. What were the key factors that made sustained Western prosperity possible? The answer presented in this book focuses upon mechanical knowledge, derived largely but not exclusively from Newtonian science, and the theoretical underpinnings that it supplied to technological innovation in mining, manufacturing, and the application of steam power more generally. The new knowledge economy displayed many cultural elements – wider circulation of information, new teaching venues, and curricular reforms – more visible first in Britain than on the Continent. None of the elements was more important than the organized body of mechanical knowledge distilled in lectures, textbooks, and curricula. It was what French observers came to call industrial mechanics and it became crucial to technological innovation. When we speak in the present about our knowledge economy, it helps to know where and when an earlier version of it began.

Stories told by economic historians

The generalization presented here about the critical importance of knowledge in breaking the Malthusian dictum challenges existing assumptions beloved by some economic historians. For example, the literature in economic history simplistically argues that Britain industrialized first because it had abundant coal. It was there for the chiseling and hauling, so entrepreneurs seized upon it. One British historian tells us that the Industrial Revolution was not economic so much as it was "physical, chemical and biological . . . a means of escape was found, by happenstance rather than conscious design initially [leading to] a rising expenditure of energy." Willy-nilly, we are asked to believe, the British began to tap the energy capital that had been locked up in coal deposits 300 million years previously. Industries needed coal; hence it was extracted. Another version of the same argument about coal claims "the only limit on the expansion on [its] energy use is the capital accumulation required for that extraction."[1]

In the case of coal, the problem with the "capital brings success" argument rests on the inaccessibility of much of the coal, and the need for skilled engineers to figure out how to extract it from below the surface of a mine. As we will see in the chapters ahead, knowledge of basic mechanics and the running of steam engines played a decisive role in making the coal usable. In the course of the eighteenth century the tried and true methods for coal extraction were revolutionized. Skilled engineers were vital in the process, and detailed, small-scale problem-solving at mine after mine gradually expanded the tonnage extracted throughout the British Isles.[2]

Another commonplace in the economic history of the Industrial Revolution awards pride of place to semi-literate tinkerers, particularly in the vital manufacturing sector of cotton. In that older view, historians such as Pat Hudson believed "there was almost no exchange of ideas between scientists and industrial innovators. Scientific advance at the time lay mainly . . . far removed from the sphere of major industrial advances."[3] The *personae* of the earliest British entrepreneurs have been described as deficient in "technical and commercial expertise," a condition remedied in time only by employing specialists.[4] This version of economic history

1 E. A. Wrigley, "In Quest for the Industrial Revolution," *Proceedings of the British Academy*, 2003, Vol. 121, pp. 168–70. He softens this view in *Energy and the English Industrial Revolution* (Cambridge University Press, 2010), pp. 44–7. See P. Warde, "Energy and Natural Resource Dependency in Europe, 1600–1900," in C. A. Bayly *et al.*, *History, Historians and Development Policy. A Necessary Dialogue* (Manchester University Press, 2011), p. 233.

2 As predicted in F. M. Scherer, *New Perspectives on Economic Growth and Technological Innovation* (Washington, DC: Brookings Institution Press, 1999), pp. 62–4. See also P. Hudson, *The Industrial Revolution* (New York: Edward Arnold, 1992), p. 24.

3 Ibid.

4 P. L. Payne, *British Entrepreneurship in the Nineteenth Century*, 2nd edn., 1988, and found in I. A. Clarkson, ed., *The Industrial Revolution. A Compendium*, Atlantic Highlands, NJ: Humanities Press, 1990, p. 70; now available from Humanity Books, Amherst, NY.

Figure 2 A spinning jenny still in use in Trowbridge, c. 1930 © Science Museum/Science & Society Picture Library. All rights reserved

caricatured early industrialists as primarily untutored artisans for whom invention by tinkering superseded abstract knowledge of scientific or technological principles.[5] "Practical knowledge," we are told, exists divorced from "theoretical" or "abstract" knowledge. The rigidity of this model neglects the fact that early industrialists in cotton could be both artisanal and machine savvy while being theoretically sophisticated. To be sure, making spinning jennies did not necessarily require a working knowledge of mechanical principles derived from science; connecting and maintaining multiple spinning machines to steam power did.

The records in Manchester tell a much more complicated story, and again, without dismissing the skilled hand worker, show the role played by the application of mechanical knowledge to the manufacturing of cotton cloth. Turning to Leeds and its linen industry reveals a similar pattern: scientifically informed entrepreneurs in league with engineers – all mindful hands – brought new technology to the factory floors.[6]

New evidence from early American industrialization also demonstrates that technical knowledge during the late eighteenth and nineteenth centuries consisted of multiple skills of varying degrees of abstractness.[7] A new "technical literacy" sprang up along with new manufacturing technologies and included, in addition to traditional alphabetical literacy, the ability to make mathematical calculations of increasing sophistication and to read and understand technical drawings and models.[8] The earlier evidence from Britain points to a similar configuration of mathematical calculation, trial and error experimentation, and the ability to follow the complexity of new machinery.

In much post-Second World War era scholarship, we got a list of reasons why England industrialized first, and by extension why the West industrialized first. Old School economic historians told how just about everything except education and knowledge – i.e., culture – held the key to

[5] See P. Mathias, "Who Unbound Prometheus?" in P. Mathias, ed., *Science and Society 1600–1900* (Cambridge University Press, 1972).

[6] For a relevant account of the skilled tinkerer, see J. Smail, "Innovation and Invention in the Yorkshire Wool Textile Industry: A Miller's Tale," in L. Hilaire-Pérez and A.-F. Garçon, eds., *Les chemins de la nouveauté: innover, inventer au regard de d'histoire* (Paris: Éditions du CTHS, 2003), pp. 313–29. For a good description of the millwright of the mid eighteenth century see D. T. Jenkins, *The West Riding Wool Textile Industry 1770–1835* (Edington: Pasold Research Fund Ltd., 1975), pp. 101–2, quoting Fairbairn. And see P. Hudson, *The Industrial Revolution* (London: Edward Arnold, 1992), p. 24.

[7] E.W. Stevens, Jr., *The Grammar of the Machine: Technical Literacy and Early Industrial Expansion in the United States* (New Haven, CT: Yale University Press, 1995). See R. Thomson, *Structures of Change in the Mechanical Age. Technological Innovation in the United States 1790–1865* (Baltimore, MD: The Johns Hopkins University Press, 2009).

[8] Stevens, 1995, pp. 2–4. On the pedagogical and epistemological problems associated with graphical representation, see Chapter 2.

industrial development: access to coal, cheap labor, surplus population leading to increased division of labor, the slave trade, or abundant capital, or consumerism creating large domestic markets. A mono-causal determinism has dominated the debate, a universalizing discourse that basically says to the rest of the world: my way or the highway. Taking culture seriously, as it pertains to education and the inculcation of knowledge, means acknowledging complexity in history, the multiple avenues by which to escape the misery of poverty, or, more broadly, the Malthusian dictum.[9] It also valorizes the universally present human ability to know new things and to put that knowledge to work always within specific historical contexts.

One further example of determinism current early in the twenty-first century needs to be given. Contemporary economist Robert Allen argues that in Britain labor was dear and coal was cheap; hence people produced machines that saved on the first and accessed the second. The argument would seem to ignore a basic rule in economic life: for people out to make a profit, all inputs and expenditures are equally scarce. If the economists have not gotten us thoroughly confused, there is more. Other economic historians tell us that the wage data required to test the suggestion are simply not available.[10]

As we will see in Chapter 2, even though the records are spotty for the eighteenth and early nineteenth centuries, wage rates exist for coal mining. It is possible to compare wages in British coal mines with other costs incurred, and, just as important, with wages at roughly the same time in France. The comparative method employed for just one industrial site –

[9] A good start for learning about the practitioners of these economic schools and their disagreements would be R. Brenner and C. Isett, "England's Divergence from China's Yangzi Delta: Property Relations, Microeconomics, and Patterns of Development," *The Journal of Asian Studies*, 61, May 2002, pp. 609–62, taking issue with K. Pomeranz, *The Great Divergence: Europe, China, and the Making of the Modern World Economy* (Princeton University Press, 2002), who is a proponent of the demography view of economic development. Brenner and Isett emphasize property relations, free markets and consumption. These are sophisticated historiographical traditions that require careful attention. They just do not admit culture into the discussion. For a theoretical approach to culture and sharing my view of its relationship to economic life, see E. L. Jones, "Culture and Its Relationship to Economic Change," *Journal of Institutional and Theoretical Economics*, 151, 2, June 1995, pp. 269–85. On the value of admitting differences, and the tortured history of universalizing generalizations, see the entire Roundtable "Historians and the Question of Modernity," *American Historical Review*, 116, 3, June 2011, pp. 631–751, with essays by Zvi Ben-Dor Benite, Gurminder K. Bhambra, Dipesh Chakrabarty, Carol Gluck, Mark Roseman, Dorothy Ross, Carol Symes, Lynn M. Thomas, and Richard Wolin.

[10] For the claim that we cannot know wages with any certainty, see R. Fox, ed., *Technological Change. Methods and Themes in the History of Technology* (Amsterdam: Harwood Academic Publishers, 1996), p. 162. For the high wage argument, see R. C. Allen, *The Industrial Revolution in Global Perspective* (Cambridge University Press, 2009).

the coal mines of Northumberland – calls into question the high-wage argument. So, too, does the fact that wages were also high in the Dutch Republic, but industrialization occurred there nearly two generations after it did in Britain and Belgium.[11] Finally, there is overwhelming evidence that the cost of keeping workhorses proved more of a drag on profit than the wages of the miners.

Another reason for diverting attention from knowledge derives from what little we know about formal education, particularly in Britain. Part of the reason for this myopia about formal and informal education may derive from the appalling state of British educational records prior to about 1850. Making education a local matter may have many virtues, but leaving behind a paper trail is not one of them. We do know that grammar schools in places such as Manchester and Newcastle turned toward technical education after 1750, and that all over the North efforts were made to create schools. Students had to find schools generally near a manufacturing town before they could find one that would teach some science and math.[12] Yet the teachers of Latin took a dim view of anything that might displace its kingly status. It has been thought for some time that education stagnated in Britain after 1750, although that view is now widely contested.[13]

[11] The classic study on this topic is J. Mokyr, *Industrialization in the Low Countries, 1795–1850* (New Haven, CT: Yale University Press, 1976), pp. 168–89, and 218.

[12] See P. Elliott, "The Birth of Public Science in the English Provinces: Natural Philosophy in Derby, 1690–1760," *Annals of Science*, Vol. 57, 2000, pp. 61–100. And see John Rylands Library, Manchester, John Seddon MSS, Box 1/1–16, f. 12, March 7, 1756, Rev. Seddens to James Nicholson. Seddens is going up and down the country raising subscriptions to set up academies, e.g. Birmingham and Bristol. Nicholson is a merchant in Liverpool. He is distributing Locke on *Human Understanding* but also volumes of sermons; Folder #4 Rev. Holland to James Nicholson on school Holland runs in Bolton; charges 20 guineas a year exclusive of washing and ½ guinea entrance fee. Those destined for the counting house have emphasis placed on the English authors, geography, history, and math. His son will then go on to the Warrington academy after time at this school; and see Benson MSS, MS B1/26 Caleb Rotheram of Kendal to George Benson; December 24, 1733 from Kendal, "we are in need desperately of academies in the north; miserable Scots men fill in here and there because no one would employ them at home." March 6, 1734/5 he is being offered a living in Durham but wants to hear from London about his future as a tutor and the prospect of setting up an academy there in Kendal. He stays in Kendal and by 1753 he is teaching natural philosophy (see #9, November 25, 1753 same to same). In f. 10, 1735, we learn that he is teaching mathematics – "I have a distinct consideration for that branch of Instruction" – from letter to Mr. Blackstock, September 13, 1735. And for having to leave a grammar school to find one near Sheffield that taught some science, see G. Hinchliffe, *A History of King James's Grammar School in Almondbury* (Huddersfield: The Advertiser Press Ltd., 1963), p. 91. Academies or grammar schools were forms of what Americans call secondary education.

[13] See D. Mitch, "The Role of Education and Skill in the British Industrial Revolution," in J. Mokyr, ed., *The British Industrial Revolution. An Economic Perspective*, 2nd edn.

Culture and education in the new economic history

Recently reformed economic historians, led by Joel Mokyr, have come to recognize that "a small group of at most a few thousand people . . . formed a creative community based on the exchange of knowledge" and they became the "main actors" who ushered in the Industrial Revolution in the West. "Engineers, mechanics, chemists, physicians, and natural philosophers formed circles in which access to knowledge was the primary objective." Mokyr and others now recognize that rates of general literacy, while to be applauded, tell us little about the few thousand who made up the community inventing or accessing an industrial knowledge base. Those men are central to the story this book is telling. By the mid eighteenth century in Britain schoolmasters appeared in manufacturing areas offering to teach the usual subjects but also mathematics and mechanics. Some of their pupils who remain nameless and recordless may nevertheless belong to this book's cast of characters.[14]

Historians have recognized the remarkable role played by educational institutions run by British Dissenters (non-Anglican Protestants) and especially Quakers. They have also argued that the child-rearing practices of Dissenters maximized self-reliance and the desire to achieve. In the pages ahead, educational and religious backgrounds can be documented in some British cases, and, not surprisingly, Unitarians, Presbyterians, and Quakers will figure prominently, although by no means exclusively.

Nothing compares to the educational records preserved by the French state and hence we know a great deal about what the secondary schools

(Boulder, CO: Westview Press, 1999), pp. 241–79. For the defenders of Latin, see J. A. Graham and B. A. Phythian (eds.), *The Manchester Grammar School, 1515–1965* (Manchester University Press, 1965).

14 J. Mokyr, *The Gifts of Athena. Historical Origins of the Knowledge Economy* (Princeton University Press, 2002), p. 66. For British education, see CGEH Working Paper Series "The Role of Human Capital in the Process of Economic Development: The Case of England, 1307–1900," A. M. de Pleijt, Utrecht University, November 2011, Working Paper No. 21, www.cgeh.nl/working-paper-series/, accessed September 4, 2012. For an older view, no longer compatible with the evidence, see W. B. Stephens, *Education in Britain, 1750–1914* (New York: St. Martin's Press, 1998), Chapter 4. For how difficult knowing about literacy can be, see D. Vincent, "The End of Literacy: The Growth and Measurement of British Public Education since the Early Nineteenth Century," in C. A. Bayly *et al.*, *History, Historians and Development Policy*, pp. 177–92. For one such school, see P. Lord, "History of Education in Oldham" (M.Ed. thesis, University of Manchester, 1938). (Found at John Rylands University Library, Main: Thesis 7328), pp. 49–50. James Wolfenden taught school in Oldham during the eighteenth century and an advertisement for his school announced: "James Wolfenden – Private Teacher of Mathematics in Manchester and its vicinity, respectfully informs the public, that he can, at present engage a few more pupils who may be instructed in Arithmetic, Geography, and the Use of the Globes, as well as higher branches of Mathematics and their application to Mechanics."

taught in the period 1750 to 1850 in France and the Low Countries. Continental education in France and Belgium (under French control from 1795 to 1815) became a largely secular affair after 1795, and the role of Catholicism is difficult to assess in the period up to 1815.[15] In Britain, meanwhile, we can demonstrate the presence of mechanical knowledge in coal mining, in textile factories, at canals and harbors, in committees of the House of Lords, and not be able to prove where it was learned. On the Continent it is possible to access abundant educational records, and the knowledge offered in the schools can be described in detail. The last three chapters focus on these Continental sources and the mixed story that they tell about the deployment of scientific knowledge.

Armed with knowledge and know-how, inspired as much by the desire to get rich as by any other motive, entrepreneurs emerged within an industrial culture wedded to scientific knowledge and technology as the means to an unprecedented end: profit from power-driven productivity from inorganic sources. The transformation from organic to inorganic power was gradual, and in many places water and wind power remained vital well into the nineteenth century. Nowhere did the transformation in forms of energy production occur as rapidly as it did in Britain after 1750.

Now, as we sense the dangers to the global environment brought about by the gases and heat released by industrial energy, we may come to see the Industrial Revolution as an event of greater complexity than simply a means to escape abject poverty.[16] Yet given what we now know about the role of culture and education in making industrial economies, may we not also presume that knowledge will foster the creation of green economies?

Development studies and thinking outside the box of traditional economic history

At present, some experts focused on under-development believe they know what makes technological innovation happen, and emphasize its inextricable connection to science in both formal and informal sites of learning. Something else is also reasonably assumed to be certain, even if we do not agree on how it works: over the long term, knowledge and technological progress reduce poverty. When the United Nations or various economists focus on the least developed nations, they want to

[15] For child-rearing practices, see Flinn, *The Origins of the Industrial Revolution* (London: Longman, 1966), pp. 87–90.

[16] See F. A. Jonsson, "The Industrial Revolution in the Anthropocene," *The Journal of Modern History*, 84, 3, September 2012, pp. 679–96. On knowledge in relation to economic development, see Scherer, 1999, pp. 32–42.

know, among many things, what policies they employ to promote scientific and technological knowledge leading to innovation. They ask for reports about whether or not Bangladesh (or Cambodia, or Haiti, or Uganda, among over forty other nations) gives priority to science and technology. Has it developed initiatives for both in the educational system from primary and secondary to higher education? Does industrial and engineering research pay attention to technological issues; does technical and vocational training do the same?[17]

The UN asks questions in the present about the present that, despite the benefits and dangers of hindsight, we should be asking about the past. What knowledge was needed in the First Industrial Revolution, and how was it acquired, and sometimes simultaneously applied?

Not everyone asking these questions, or advising the least developed nations, has a workable understanding of how knowledge is transmitted. They adopt a mechanistic perspective on science, technology, and contemporary poverty. They tell developing nations just to take what they can get from more technologically advanced markets or nations, and assume that access to foreign technology is equivalent to its effective use. Information, knowledge, and learning, regardless of their source or cultural context, translate into productivity. This top-down conception of knowledge ignores the fundamentally dynamic character and plural contours shaping its production and generation. The mechanistic perspective assumes that knowledge is socially disembodied and universally transferable. It ignores the

[17] M. Mackintosh, J. Chataway, and M. Wuyts, "Promoting Innovation, Productivity and Industrial Growth and Reducing Poverty: Bridging the Policy Gap," *Special Issue of The European Journal of Development Research*, 19, 1, 2007. See *The Least Developed Countries Report, 2007. Knowledge, Technological Learning and Innovation for Development*, United Nations Publications, Autumn 2007; for a copy see http://unctad.org/en/docs/ldc2007_en.pdf, accessed December 4, 2012.

For the recent statistics where a least developed country is defined as having a gross national income per capita of above $900 and less than $1,086, see United Nations Conference on Trade and Development, *The Least Developed Countries. Report 2009. The State and Development Governance* (New York: United Nations, 2009), and see p. 163, "the modern form of industrial policy is indispensable for articulating the links between science, technology and economic activities, through networking, collaboration, and fine-tuning and learning components (learning by doing, adaptive R&D, and labor training.)" In 2008 the lower threshold income was $750. For the experts, see R. G. Lipsey *et al.*, *Economic Transformations. General Purpose Technologies and Long Term Economic Growth* (New York: Oxford University Press, 2005); Mokyr, 2002; J. Horn, *The Path Not Taken. French Industrialization in the Age of Revolution 1750–1830* (Cambridge, MA: MIT Press, 2006); H. Nowotny, ed., *Cultures of Technology and the Quest for Innovation* (New York: Berghahn Books, 2006); and the essay by H. U. Vogel, "The Mining Industry in Traditional China: Intra- and Intercultural Comparisons," pp. 167–90. See also M. C. Jacob, "Mechanical Science on the Factory Floor: The Early Industrial Revolution in Leeds," *History of Science*, 45, 148, 2007, pp. 197–221. This issue of the journal is devoted entirely to a discussion of Mokyr's *The Gifts of Athena*.

values, components, and processes, such as literacy rates or access to printing, that shape its generation; it also ignores history. Knowledge becomes human capital when we "own" it, and that happens through bottom-up education, formal, informal, on the shop floor, in the home – whatever works. Historical research tells us that Britain experienced a sustained increase in primary and secondary (what it called grammar) schooling around 1750. It was also the first Western nation to industrialize.[18]

Such a cultural inquiry into innovation has its critics. An historian of India finds this kind of analysis, with its emphasis on applied science, inherently Eurocentric. Many who do not understand the approach may say the same. By highlighting industrial mechanics we denigrate the scientific fertility of other parts of the world, or so the argument runs. If areas outside of Western Europe lacked such expertise, then we must be arguing that they were somehow inferior, that something went wrong and the science that was practiced in India or China or the Ottoman Empire can be ignored or devalued. To make the case that historians of Western science are Eurocentric and mean-spirited about the rest of the world, a caricature of Western science around 1750 has to be invented. Western science must be rarefied. Rather, it should be seen as a mélange of various interventions into nature, as indigenous and bottom-up – not, as was the case in India, the work of rulers and their courtiers. Prasannan Parthasarathi argues incorrectly that Western science was everywhere controlled by government administrators or experts who were rigorously mathematical, experimental, and above all rational (whatever that means). The complexity of science, as distilled by textbooks, technical hands-on knowledge, and technological innovation, disappears in his account.

Parthasarathi accuses those who study science and the Industrial Revolution of denigrating the inventiveness of the non-Western. Botanical innovations from India, medical procedures from China, modern surveying techniques from South Asia, Sanskrit texts (some yet to be deciphered), Indian astronomy, mathematics, military technology, European and Asian interactions – Parthasarathi argues – made non-European science just as vital as what existed in the West. This author is not denying the vitality of non-Western scientific traditions; they just do not explain the role of the first knowledge economy in Western industrial development. Knowing about non-Western innovativeness does not, however, help to explain why industrial mechanics and unprecedented economic development appeared first

[18] F. Machlup, *The Economics of Information and Human Capital* (Princeton University Press, 1984), pp. 430–52. Flinn argues that the lack of capital and technical skill, plus an unwillingness to accept "the social disruption which inevitably accompanies" new technology, can explain its failure in underdeveloped countries; see Flinn, 1966, p. 69.