

What *really* happened in the English Industrial Revolution?

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1 Introduction

As early as 1734, at least, observers of the economic panorama, later including economic and other historians, have commented on the role of energy inputs in economic activity and its social outcomes. These comments are not always directly related to energy, but their implications often are. Jean Theophilus Desaguliers (1734), a member of the Royal Society and “natural philosopher” (physicist and engineer), observes that, to wit, using human labor to pump water from coal mines was not profitable. He recommends “fire engines” (steam engines) to solve that problem. This is a clear call to substitute a cheaper energy input, coal, for more expensive human and animal energy inputs to pump water from flooding coal mines.

Friedrich Engels (1892), writing of 1844 England, asserts that the invention of the steam engine and machines for spinning and weaving cotton gives the impetus to the Industrial Revolution, and changes the entire social structure of middle-class society. William Stanley Jevons (1865) frets that England will lose its economic dominance when the coal supply runs out, perhaps an early version

of today's "peak oil" concerns. Later, Edwin Eckel (1921) reports coal reserve estimates for several major economies, and makes the important claim that World War I is significantly about resources including, importantly, coal. Frederick Soddy, a 1921 Nobel Laureate in chemistry, writes widely on economics rooted in principles of physics and thermodynamics (1911, 1921, 1931, 1933, 1934), presaging Herman Daly and Nicholas Georgescu-Roegen.

John Nef, in a two-volume history of the coal industry in Britain (1932), has a strong sense of the importance of energy consumption, primarily from coal, in the growth of the British economy through an extended period from the sixteenth century on. He also describes in depth how the coal industry influences the rise of industrial capitalism.

Paul Mantoux (1961), a French historian, writes in the early twentieth century of the machine industry transition in England during the eighteenth century with deep analyses of the key industries, especially wool and cotton textiles.

Later in the twentieth century, W. Fred Cottrell (1955) writes about energy sources from the neolithic through nuclear energy. Cottrell uses an unusual syntax in describing this history: low-intensity energy converters for humans and animals, and high-intensity energy converters for machines. Peculiarly he never, as far as I could find, uses the word "capital," just high-intensity energy converter. He thus focuses clearly on the distinction between low-capacity muscle-powered work and high-capacity machine-powered work, an essential distinction I will make later in discussing industrial revolutions. He also discusses the impact each of the energy sources makes on society.

The Italian economic historian Carlo Cipolla (1961, 1962, 1966) writes widely of energy revolutions including neolithic agriculture, the early modern European sea dominance, and the Industrial Revolution. Cipolla is an early chronicler of the roles various technologies played in these revolutions, in a sense presaging Joel Mokyr (1992).

Nicholas Georgescu-Roegen (1971) focuses on the thermodynamic foundations of economic systems, and helps found the field of ecological economics. This seemingly stark description of

our activities holds an important truth: all economic activities, indeed all activities, require energy inputs. We can imply from this that limited energy inputs will limit economic outputs. Following his thinking, I sometimes think that the only non-substitutable input is energy (as in Joules); energy sources can be substituted, but you must have Joules for life and economic activity. Energy source substitution becomes fundamental to my story of industrial revolutions. Timothy Garrett (2009, 2012, 2015) advances a modern treatment of this energy-based thermodynamic work including its impact on long-range climate forecasts.

Focusing back on England, E. A. Wrigley (1988, 2010) writes extensively about England's transformation from an "advanced organic" society mainly engaged in agriculture to an "industrial inorganic society" engaged primarily in non-agricultural production in centralized factories. Wrigley interweaves the social impacts into this story, very notably how it influenced the transition away from Malthusian demographic dynamics to a post-Malthusian dynamic. The Industrial Revolution eventually changed the sign of the correlation between increased living standards and fertility rates from positive to negative, a change that holds profound implications for our economic future.

What I call an energy revolution, or energy revolutions, Italian economic historian Paolo Malanima (2010) calls a transformation of the energy system. His time frame is the same as John Nef's and mine – from the sixteenth century through the nineteenth century. Malanima sketches out formally the essential features of this transition that I focus on for England and China in this paper. These include population growth, rising energy costs, and substitutions of heat and muscle power energy sources across Europe. He does this at a macroeconomic level. My focus on England allows me to explain in depth the energy foundations of the first Industrial Revolution, examine why they happened in England, endogenously, and describe both the microeconomic incentives behind the revolution, hinted at by Desaguliers, and its macroeconomic phases.

The twenty-first century has seen some very important work among historians relating energy inputs and growth. Kenneth Pomeranz, a sinologist who, like William McNeill, is a "world" histo-

rian, but unlike McNeill (1963), focuses on explaining the “great divergence” between China and England starting around 1800 (2001, 2002). Pomeranz explains why the English did the Industrial Revolution first compared to anyone else, especially China, by invoking the English advantages in coal, colonies and cotton. Coal removed the energy constraint faced by all growing economies from depending on wood for heat and, potentially, steam. The English colonies provided both input resources such as cotton, and (colonial) consumer markets for absorbing the increased capacity as production constraints dissolved in the face of steam-powered factories. This is a classic case of Adam Smith’s vent-for-surplus theory (1904) that Pomeranz invokes along with armed mercantilism as instrumental to the England’s successful industrialization. But very clearly, he returns many times to the central fact: England was geographically and geologically lucky to have cheaply accessible coal supplies. The English Industrial Revolution was foremost an energy revolution.

Economic historian Robert Allen (2009) usefully intensified the explanation of the English Industrial Revolution as an English energy revolution. Allen’s approach is data-intensive; in particular he presents wage and energy cost series for England, China, and other important economies in the early and late modern eras. This allows him to construct a comparative wage-to-energy-price ratio for these areas in a critical proto-industrial era that not only answers the “why England and not China” question surrounding the Industrial Revolution, but allows one to begin formalizing a theory of Industrial Revolutions, or even more generally, a new approach to growth theory. I do so in this paper.

Allen’s analysis bolsters the “energy revolution as primary” approach that I am exploring; he summarizes his view strikingly: “... there was only one route to the twentieth century – and it traversed northern Britain” (2009:275). His essentialist view is that expensive English wages and cheap coal energy from Newcastle, though a historical accident, were the uniquely English causes for the Industrial Revolution and modern economic growth.

As a researcher of energy’s role in development and growth, it sometimes feels like culture

and institutions dominate the explanations, with a minor role, if any, given to energy consumption. While the scholars and observers cited above place energy consumption at the center of their explanations for the English Industrial Revolution and modern economic growth, they rarely do so explicitly. The most explicit are W. Fred Cottrell (1955), Robert Allen (2009), E. A. Wrigley (1988, 2010), and Vaclav Smil (1994, 2008) not mentioned above but a scientist and scholar with a very broad understanding of energy's role in society. The others cited represent a group of scholars who at least hint at the primary role energy plays in the *sui generis* English experience.

Arrayed against this countably small group of major scholars is a vast literature on the role of culture and institutions in explaining why England succeeded in its industrial revolution before anyone else was able to do so. I will review the very high points of this literature, and then turn to a review of relevant Chinese literature as representing a “natural experiment” to compare with England.

My purpose is to move the role of energy consumption and revolutions to its use to the center of discussions on the English Industrial Revolution, and more generally, on industrial revolutions and economic development and growth. While this necessarily displaces culture or institutions as prime causes of these events, I believe the evidence and theory I develop makes the resitutation justifiable.

Representative of the vast institutional literature on the English Industrial Revolutions, I first must include Max Weber (1964, 2002) who clearly is an early eurocentric scholar, invoking European Protestantism as a motivating force for capitalism and the events that flowed from it.

Continuing, David Landes (1969, 1999) writes widely on Western culture as primal in the Industrial Revolution. Landes, as many scholars do, discusses the role of energy and the technologies that enable its use, but returns to culture for the reason for the rise of the West. A more recent approach to this theme is a series of books by Deirdre McCloskey (2007, 2010) discussing the primacy of Western values, ethics, and culture in the comparative rise of the West; McCloskey does talk about the importance of coal, but it is a glancing discussion.

Douglass North, an economic historian instrumental in founding both New Economic History (Cliometrics) and New Institutional Economics, works on the broad issues of economic growth and development. He takes a very historical approach, describing market expansion from tribal local exchange dominated by informal rules to long-distance trade which required new institutions to deal with the problems of agency (not having physical control of the goods) and contract (providing transport protection and enforcement of contracts).

North (1973, 1990) focuses on the idea that economies require “efficient organization” to grow, a self-admittedly neo-classical approach. Efficiency entails developing sufficient institutional arrangements to create individual incentives to inventors and producers. The most important institution is property rights. The West necessarily developed these institutions as conditions for its rise. He discusses both extensive growth, overall growth because of increases in the traditional factors of production (land, labor, capital), and intensive or per-capita growth which for him is true economic growth. Intensive growth is in turn caused by either per-capita increases in factor inputs, or increased productivity through economies of scale, education, capital improvements via technology embedding, and reducing market imperfections. He answers the puzzle of why, given the straightforward prescription above, every economy has not developed economically. And, of course, it is because they are not efficiently organized, lacking required institutions, most importantly property rights. North also comments on population growth as being important to economic growth; this important insight helps explain the basic motivation for inventors and entrepreneurs to invent and produce – population growth leads to increasing consumer demand from which all production and input demands are derived.

Jack Goldstone, a member of the “California School” of economic history, writes widely (1987, 2000, 2008) on the West’s cultural primacy allowing its comparative rise. In particular (2002), he develops the concept of “Efflorescence,” or the asymmetric rise of economic activity among nations due to institutional differences. To illustrate, he invokes the difference between North and South

Korea since their partition and radical institutional divergence.

Daron Acemoglu's work represents a modern, quantitative, version of this school; in particular he studies the role of the state (2005), growth theory (2012), and institutions as causing growth (2005b).

The defining point of view for this group is that, while (for some) certainly there was something that happened to the energy system, the causes of the English Industrial Revolution and subsequent rise of the West were cultural and institutional. In this paper I appeal to something even more fundamental, and develop the view that while institutions are important, they arise in response to underlying economic changes. Therefore we must study those to truly be able to answer North's puzzle of "why not everyone?"

The "culture and institutions *are* growth and development" group's view was not the first institutional approach to the question. Karl Marx (1904) and Thorstein Veblen (2009) among other original institutionalists viewed institutional development as endogenous to the major economic developments. This is a point of view I have come to share and will develop in this paper.

Now I turn attention to China as an important "natural experiment" comparison to England in order to test my hypotheses about growth and industrial revolutions. If in, say, 1400 a group of growth economists at a conference were sitting at the bar and speculating on what country was likely to accomplish the first industrial revolution, China almost surely would have been in the lead. Large markets, one-quarter of global population, more than one-quarter of global GDP, and important inventions are among several important drivers legitimizing China as the leader in the gathering race toward industrialization. Some had never heard of England – it was a small, even backwater, economy near the Eurasian land mass. Yet three centuries later England was accelerating along its path of becoming the leading economy in the world. And by 1800 was clearly diverging from China and in the global economic lead.

The Chinese "energy" story is not nearly as well-developed as the English possibly because

China did not experience an industrial revolution and generated all the questions related to that event that England did. And the cultural and institutional story surrounding China became ossified for many years as the answer to the puzzle the economists in 1400 were discussing. This very Eurocentric attitude is best summarized by Marx as the “Asiatic mode of production,” by which Marx (and Engels) describe Asia as consumed by despotic rulers expropriating surplus from the economy, monopolizing land ownership, controlling irrigation systems, and thus preventing modern economic development. This ossification story is too simplistic and is increasingly remedied by modern scholars that I will review.